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NRC's Use of Level 3 PRA Information in Severe Accident Mitigation Alternatives Reviews

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IAEA Conference on Level 3 PRA

Vienna, Austria

July 3, 2012

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Presentation Outline

- Introduction and background
- Definition and scope of SAMAs and SAMDAs
- Current status of SAMA and SAMDA reviews
- Major steps in a SAMA evaluation
- Example from a new reactor SAMDA/SAMA evaluation
- Insights

Introduction and Background

- Level 3 PRAs have not been required by the NRC, but are by far the best way to meet other requirements:
  - The U.S. Court of Appeals decision, in Limerick Ecology Action v. NRC, 869 F.2d 719 (3rd Cir.1989), requires the NRC to consider severe accident mitigation design alternatives (SAMDAs) in the environmental impact review performed under Section 102(2)(c) of NEPA.
  - All applications for license renewal must consider not only SAMDAs but mitigation alternatives arising from potential changes to procedures and training programs. All of these taken together are called Severe Accident Mitigation Alternatives (SAMA).
  - For new reactor designs, the NRC all applications must evaluate severe accident prevention and mitigation design features. Part of this requirement includes evaluating SAMDAs and documenting the evaluations in environmental reports.

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Definition and Scope of SAMA

- SAMA = A feature or action that would prevent or mitigate the consequences of a severe accident
- Includes: Hardware modifications (design features), procedure changes, and training program improvements
- SAMDA includes only design features
- Prevention and mitigation
- Both internal and external events

- **Risk models and insights play key roles, but SAMA evaluations are not risk-informed licensing actions**

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Status of SAMA and SAMDA reviews

- Completed SAMDA evaluations for 3 sites during initial licensing in 1989-1995
- Completed SAMDA evaluations for multiple advanced light-water reactor design certifications (DCs) and combined construction and operating licenses (COLs)
- Completed SAMA evaluations for > 50 units for license renewal, including:
  - All BWR containment/NSSS types in US, except Mark-III / General Electric Type 6
  - All PWR containment/NSSS types in US

Major steps in a SAMA evaluation

- Identify leading contributors to risk
  - Use plant-specific risk study or equivalent
  - External events considered to the extent practicable
  - MACCS2 used to determine offsite consequences
- Identify candidate SAMAs
  - Identify SAMAs, including low-cost options
  - Use PRA importance measures to identify important basic events
  - Utilize relevant past SAMA evaluations
- Estimate risk reduction / implementation costs
  - Calculate maximum attainable benefit (MAB), also known as maximum averted cost
  - Perform benefit assessment and cost assessment
  - Screen out SAMAs that can't be cost-beneficial

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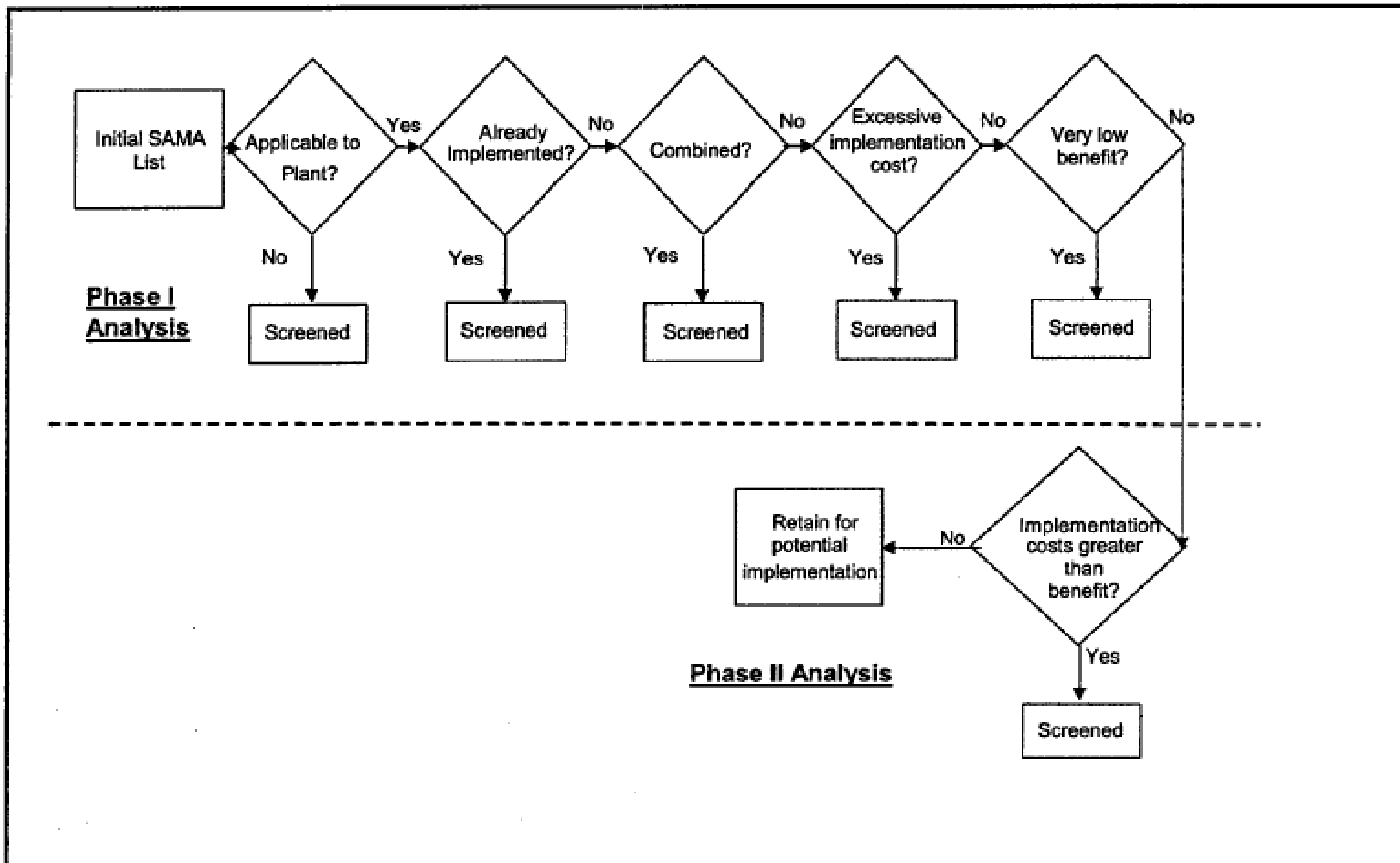
Major steps in a SAMA evaluation (continued)

- Determine potentially cost-beneficial SAMAs
  - Estimate net value of SAMA (averted costs –cost of enhancement)
  - NUREG/BR-0058 and NUREG/BR-0184
- Do more detailed analysis for remaining SAMAs
  - More realistic evaluation of benefits
  - More detailed implementation cost development
  - Assess effects of uncertainties
- Further Guidance
  - ESRP (NUREG-1555, Supp 1)
  - NEI-05-01, Revision A, “SAMA Analysis Guidance Document” (endorsed by NRC Interim Staff Guidance LR-ISG-2006-03)

SAMA Screening Process (from NEI-06-05)

SAMA Screening Process



External Events and Uncertainty

- The SAMA analysis uses a simplified approach to account for external events and analysis uncertainties
  - Benefits are typically quantified using the internal events model and then multiplied by the ratio of total CDF to internal event CDF (typically a factor of about 2 but could be as high as 10) to account for external events benefit
  - Impact of uncertainties on the results of the SAMA analysis are assessed through an additional multiplier. Multiplier typically based on the ratio of the 95%ile CDF to the mean or point estimate CDF (typically a factor of about 2).
  - Any SAMAs that become cost beneficial with uncertainties are included as potentially cost-beneficial SAMAs.

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Maximum Attainable Benefit (MAB):

The Total Cost Impact of a Severe Accident

- Determined by summing the occupational exposure cost, on-site cost, public exposure, and off-site property damage.
- All severe accident initiators must be accounted for, including both internal and external events at power, and events initiated during shutdown.
- Sensitivity studies are also carried out for certain parameters, such as the discount rate, dose uncertainties, cleanup costs, and inflation rates for replacement power costs.

Cost/Benefit Evaluation of SAMDAs

- The net value of a design alternative is the difference between the MAB (from averting all severe accidents) and the cost of the enhancement.
- The methodology used is based on the NRC's guidance for performing cost/benefit analysis in NUREG/BR-0058 and NUREG/BR-0184.
- For a SAMDA to be cost-beneficial for a certified design, it must cost less than the maximum benefit.
- Cost-beneficial SAMAs are often identified during license renewal process
- To date, nothing has even been close for any of the designs submitted for certification.

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Cost/Benefit Methodology Considers Averted Onsite, Offsite, and Replacement Power Costs

Net Value = (APE + AOC + AOE + AOSC) - COE

Where:

APE	=	present value of averted public exposure ($)
AOC	=	present value of averted offsite property damage costs ($)
AOE	=	present value of averted occupational exposure costs ($)
AOSC	=	present value of averted onsite costs ($), including cleanup and decontamination, and long-term replacement power costs.
COE	=	cost of enhancement ($)

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Cost-Benefit Input Parameters

- Present value factor (from NUREG/BR-0184).

$$C = \frac{e^{-rt_i} - e^{-rt_f}}{r}$$

where,

r is the discount rate (%/yr)

t_f is the facility life (yrs)

t_i is the time before facility begins operating (yrs)

Assume 7%, 60 years, and 0 for these parameters

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Cost-Benefit Input Parameters (cont)

- Monetary valuation of accident-related health effects
  - Generally assumed to be $2,000 to $3,000 per person-rem for the year in which exposure occurs, discounted to the present value (NUREG/BR-0184).
- On-site Cleanup Period
  - 10 years assumed

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Averted Public Exposure (APE)

- Determine the off-site dose, in person-rem per year, within a 50-mile radius using MACCS2, for releases from representative severe accident scenarios evaluated in the design Level 3 PRA.
  – A set of release categories is defined in the PRA for this purpose, with a frequency of occurrence and a set of fission product release fractions for each.
  – The sum of the frequencies must equal the core damage frequency.
  – Site-specific population and meteorological data are also used.

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Averted Off-site Property Damage Costs (AOC)

- Is determined using: $AOC = C Z_t$

  AOC = averted off-site property damage costs associated with a severe accident ($)

  C = present value factor (yr)

  Z_t *= monetary value of economic impact per year before discounting ($/yr)*

- The MACCS2 results are the economic impacts for each release category. These are summed to obtain the total monetary value of economic impact per year.

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New Reactor SAMDA and SAMA Reviews

- Regulations
- Review Process
- US-APWR and Comanche Peak 3 and 4 Example

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Regulations Pertaining to SAMDA and SAMA for DC, ESP, and COL Applications

- 10 CFR 51.55(a): A DC applicant shall submit an ER that addresses the costs and benefits of severe accident mitigation design alternatives, and the bases for not incorporating them in the design to be certified.
- 10 CFR 51.30(d) describes the scope of the NRC's Environmental Assesment for a certified design.
- 10 CFR 51.50(c) states that an ER shall be submitted by an applicant for an ESP or a COL that contains information specified in 10 CFR 51.45, including cost/benefit assessments relevant to mitigation features.

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Regulations Pertaining to SAMDA and SAMA for DC, ESP, and COL Applications (cont)

- 10 CFR 52.47(a)(23) and 10 CFR 52.79(a)(38), require the inclusion of a description and analysis of design features for preventing and mitigating severe accidents in DC and COL FSARs, respectively.
- 10 CFR 52.47(b)(2) requires that the DC application include an environmental report as described in 10 CFR 51.55.

EXAMPLE

Comanche Peak 3 and 4

US-APWR Design

Identify Leading Contributors:
Release Category Descriptions

Designator	Description	Release Frequency (per reactor-year)
RC1	Containment Bypass Includes SGTR initiating events and induced SGTR.	7.5E-09
RC2	Containment Isolation Failure	2.1E-09
RC3	Containment Failure Before Core Damage Overpressure due to loss of containment heat removal.	2.0E-08
RC4	Early Containment Failure Due to dynamic loads including early hydrogen combustion, steam explosions, and DCH.	1.1E-08
RC5	Late Containment Failure Includes late overpressure, hydrogen combustion, and basemat melt-through	6.5E-08
RC6	Intact Containment No containment failure. Releases at design leak rate.	1.1E-06
Total		1.2E-06

Elements Included in Each MACCS2 Fission Product Group

Group Release Class (Isotopes Included)

1 Noble Gases (Kr, Xe)
2 Iodine (I)
3 Cesium (Cs, Rb)
4 Tellurium (Te, Sb)
5 Strontium (Sr)
6 Ruthenium (Co, Mo, Tc, Ru, Rh)
7 Lanthanum (Y, Zr, Nb, La, Pr, Nd, Am, Cm)
8 Cerium (Ce, Np, Pu)
9 Barium (Ba)

TABLE 7.2-3 of CPNPP 3 and 4 Environmental Report: US-APWR SOURCE TERM RELEASE FRACTIONS

Release Category[b]	Plume No.	Kr/Xe	I	Cs	Te/Sb	Sr	Ru	La	Ce	Ba
RC1[c],[d]	1	9.4E-1	2.8E-1	2.0E-1	1.3E-1	4.9E-3	1.8E-2	2.4E-4	2.8E-4	1.2E-2
RC1[e]	2	7.6E-3	6.3E-3	1.1E-2	8.5E-3	3.9E-3	4.3E-3	2.7E-3	1.9E-3	3.6E-3
RC2[f]	1	9.7E-1	6.8E-2	2.6E-2	4.3E-2	5.4E-3	1.6E-2	4.0E-3	2.3E-3	8.6E-3
RC2	2	2.7E-2	2.1E-1	1.7E-2	3.5E-2	2.3E-3	1.0E-4	1.1E-4	4.1E-4	2.6E-3
RC3[g]	1	9.9E-1	4.8E-1	4.7E-1	4.3E-1	4.4E-2	2.8E-1	1.6E-3	6.4E-3	1.1E-1
RC3	2	2.0E-3	1.3E-3	1.1E-3	4.3E-3	4.9E-4	1.8E-4	6.6E-6	6.3E-5	2.5E-4
RC4[h]	1	1.0E+0	5.5E-2	4.2E-2	5.3E-2	4.8E-3	2.7E-2	1.2E-4	3.7E-4	2.4E-2
RC4	2	3.8E-4	1.4E-2	4.5E-3	1.1E-2	1.3E-3	1.1E-5	1.5E-5	4.7E-4	4.7E-4
RC5[i]	1	9.6E-1	2.5E-2	5.3E-3	9.0E-3	8.2E-5	1.0E-4	3.0E-5	1.9E-5	6.8E-5
RC5	2	2.5E-2	1.2E-1	1.5E-2	7.7E-3	2.2E-6	2.6E-6	5.9E-8	5.9E-8	5.0E-6
RC6[j]	1	7.8E-4	1.7E-6	1.7E-6	1.3E-6	1.7E-7	6.4E-7	3.5E-9	5.6E-9	2.7E-7
RC6	2	1.3E-3	1.9E-9	0.0E+0	6.0E-10	6.5E-11	4.4E-11	4.6E-13	1.2E-12	6.4E-11

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US-APWR Plume Characterization Data

Release Category (a)	Plume No.	Number of Plume Releases	Risk-Dominant Plume	Ref Time[b]	Plume Heat (W)	Plume Release Height (m)	Plume Duration (s)[c]	Plume Delay (s)[d]
RC1	1	2	1	0.0	0	0	3.6E+4	1.0E+5
RC1	2	2	1	0.5	0	0	8.6E+4	1.2E+5
RC2	1	2	1	0.0	0	0	5.3E+4	9.0E+3
RC2	2	2	1	0.5	0	0	8.6E+4	4.2E+4
RC3	1	2	1	0.0	0	0	4.4E+4	1.7E+5
RC3	2	2	1	0.0	0	0	8.6E+4	2.1E+5
RC4	1	2	1	0.0	0	0	3.2E+4	7.8E+4
RC4	2	2	1	0.5	0	0	8.6E+4	9.4E+4
RC5	1	2	1	0.0	0	0	6.0E+4	1.9E+5
RC5	2	2	1	0.5	0	0	8.6E+4	2.0E+5
RC6	1	2	1	0.0	0	0	7.3E+4	1.3E+3
RC6	2	2	1	0.5	0	0	8.6E+4	1.5E+4

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TABLE 7.2-5
SEVERE ACCIDENT ANALYSIS RESULTS SUMMARY WITHIN 50 MI OF CPNPP SITE[(a)]

Met Data Year	Dose Risk (person-rem/ RY)	Dollar Risk ($/RY)	Affected Land (hectares) [(b)]	Early Fatalities (per RY)	Latent Fatalities (per RY)	Water Ingestion Dose Risk (person-rem/ RY)
2001	2.21E-01	5.78E+02	2.66E-02	7.49E-08	1.85E-04	1.62E-02
2003	2.71E-01	6.62E+02	2.76E-02	7.43E-08	2.15E-04	1.52E-02
2006	3.00E-01	7.06E+02	2.70E-02	6.73E-08	2.39E-04	1.63E-02

a) All data are compiled from Tables 7.2-9, 7.2-10, and 7.2-11.

b) This value reflects the sum of affected land areas that have been multiplied by their release category frequency, whereas the affected land areas shown in the MACCS2 analysis are neither multiplied by release category frequency or summed. However, the same MACCS2 data were used as the basis for both values.

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TABLE 7.2-6
MEAN VALUE FOR TOTAL DOSE RISK ASSESSMENT IN PERSON-REM/RY

Release Category	Frequency (per RY)	Dose Risk - 2001	Dose Risk - 2003	Dose Risk - 2006
RC1	7.5E-09	2.39E-02	2.90E-02	2.93E-02
RC2	2.1E-09	4.62E-03	5.61E-03	6.09E-03
RC3	2.0E-08	7.56E-02	8.10E-02	8.96E-02
RC4	1.1E-08	2.24E-02	2.66E-02	2.67E-02
RC5	6.5E-08	9.36E-02	1.27E-01	1.48E-01
RC6	1.1E-06	9.97E-04	1.18E-03	1.01E-03
Total	1.2E-06	2.21E-01	2.71E-01	3.00E-01

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TABLE 7.2-7
DOLLAR RISK ASSESSMENT IN DOLLARS/RY

Release Category	Frequency (per RY)	Dollar Risk - 2001[a]	Dollar Risk - 2003[a]	Dollar Risk - 2006[a]
RC1	7.5E-09	8.10E+01	9.08E+01	9.90E+01
RC2	2.1E-09	1.12E+01	1.47E+01	1.65E+01
RC3	2.0E-08	2.96E+02	3.18E+02	3.38E+02
RC4	1.1E-08	4.64E+01	5.23E+01	5.73E+01
RC5	6.5E-08	1.43E+02	1.87E+02	1.95E+02
RC6	1.1E-06	4.96E-03	7.46E-03	6.84E-03
Total	1.2E-06	5.78E+02	6.62E+02	7.06E+02

a) The dollar risk accounts for the costs of evacuation, crops contaminated and condemned, milk contaminated and condemned, decontamination of property, and indirect costs resulting from the loss of use of property and incomes. The 2001, 2003, and 2006 refer to the year of meteorological data used in the calculation.

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TABLE 7.2-11
SEVERE ACCIDENT IMPACTS TO THE POPULATION AND LAND USING 2006 METEOROLOGICAL DATA

Release Category	Core Damage Frequency (per RY)	Dose-Risk (person-rem/RY)	Number of Early Fatalities (per RY)	Number of Latent Fatalities (per RY)	Affected Land Area (hectares)[(a)]	Cost-Risk (dollars/ RY)[(b)]	Water Ingestion Pathway (person-rem/ RY)
RC1	7.5E-09	2.93E-02	1.99E-09	1.97E-05	2.05E-03	9.90E+01	1.91E-03
RC2	2.1E-09	6.09E-03	2.46E-10	4.39E-06	7.01E-04	1.65E+01	1.27E-04
RC3	2.0E-08	8.96E-02	6.46E-08	1.27E-04	5.28E-03	3.38E+02	1.21E-02
RC4	1.1E-08	2.67E-02	4.70E-10	1.65E-05	2.44E-03	5.73E+01	6.90E-04
RC5	6.5E-08	1.48E-01	0.00E+00	7.09E-05	1.65E-02	1.95E+02	1.45E-03
RC6	1.1E-06	1.01E-03	0.00E+00	5.26E-07	7.69E-06	6.84E-03	2.41E-06
Total	1.2E-06	3.00E-01	6.73E-08	2.39E-04	2.70E-02	7.06E+02	1.63E-02

a) These values reflect affected land areas that have been multiplied by their release category frequency; whereas, the affected land areas shown in the MACCS2 analysis are not multiplied by release category frequency. However, the same MACCS2 data were used as the basis for both values.

b) The cost-risk accounts for the costs of evacuation, crops contaminated and condemned, milk contaminated and condemned, decontamination of property, and indirect costs resulting from the loss of use of property and incomes.

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TABLE 7.2-14
TOTAL SEVERE ACCIDENT HEALTH EFFECTS USING 2006 METEOROLOGICAL DATA[b]

Accident Type	Core Damage Frequency (per RY)[a]	Scaling Factor	Dose-Risk (person-rem/RY)	Number of Early Fatalities (per RY)	Number of Latent Fatalities (per RY)	Water Ingestion Pathway (person-rem/RY)
Internal Events	1.2E-6	1	3.00E-01	6.73E-08	2.39E-04	1.63E-02
Internal Fire	1.8E-6	1.50	4.50E-01	1.01E-07	3.59E-04	2.45E-02
Internal Flood	1.4E-6	1.17	3.51E-01	7.87E-08	2.80E-04	1.91E-02
LPSD	2.0E-7	0.167	5.01E-02	1.12E-08	3.99E-05	2.72E-03
Total	4.6E-6	-	1.15E-00	2.58E-07	9.17E-04	6.25E-02

a) Core damage frequency values are from Table 5 of the DC Applicant's Environmental Report (MHI 2007).

b) The values for internal fire, internal flood, and LPSD are calculated as described on page 7.2-7.

Candidate SAMDAS for Phase II analysis

1. Provide additional dc battery capacity (at least one train of emergency dc power can be supplied for more than 24 hours.)
2. Provide an additional gas turbine generator (at least one train of emergency ac power can be supplied more than 24 hours.)
3. Install an additional, buried off-site power source
4. Provide an additional high pressure injection pump with independent diesel (with dedicated pump cooling)
5. Add a service water pump (add independent train)
6. Install an independent reactor coolant pump seal injection system, with dedicated diesel (with dedicated pump cooling)
7. Install an additional component cooling water pump (add independent train)
8. Add a motor-driven feedwater pump (with independent room cooling)
9. Install a filtered containment vent to remove decay heat
10. Install a redundant containment spray system (add independent train)

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Value of Risk Averted for US-APWR Design

Table 1 – US-APWR Value of Risk Avoided

Cost Component	Internal Events	Internal Fire	Internal Flood	LPSD	Totals for All Events
Offsite Exposure Cost	$7.6k	$11.4k	$8.9k	$1.3k	$29.1k
Offsite Property Damage Cost	$0.1k	$0.2k	$0.1k	$0.02k	$0.5k
Onsite Exposure Cost	$0.6k	$0.9k	$0.7k	$0.1k	$2.3k
Cleanup and Decontamination Cost	$18.2k	$27.3k	$21.3k	$3.0k	$69.8k
Replacement Power Cost	$48.9k	$73.4k	$57.1k	$8.2k	$187.6k
Total (Maximum Averted Cost Benefit)	$75.5k	$113.2k	$88.1k	$12.6k	$289.3k

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SAMDA Benefit Sensitivity Analyses

Each SAMDA benefit is derived by multiplying each ratio of contribution to decrease CDF or LRF and the maximum averted cost together. Baseline is 7% discount rate.

	Design Alternative	Cost Impact	Maximum Averted Cost	Sensitivity of each SAMDA benefit			
				Baseline	Discount rate		Monetary equivalent of unit dose ($3000/person-rem)
					5%	3%	
1	Provide additional dc battery capacity	$2,000k	$289k	$116k	$188k	$304k	$124k
2	Provide an additional gas turbine generator	$10,000k		$116k	$188k	$304k	$124k
3	Install an additional, buried off-site power source	$10,000k		$118k	$193k	$312k	$127k
4	Provide an additional high pressure injection pump with independent diesel	$1,000k		$150k	$244k	$395k	$161k
5	Add a service water pump	$5,900k		$72k	$118k	$190k	$78k
6	Install an independent reactor coolant pump seal injection system, with dedicated diesel	$3,800k		$136k	$221k	$357k	$146k
7	Install an additional component cooling water pump	$1,500k		$72k	$118k	$190k	$78k
8	Add a motor-driven feed-water pump	$2,000k		$101k	$165k	$266k	$109k
9	Install a filtered containment vent to remove decay heat	$3,000k		$173k	$282k	$455k	$186k
10	Install a redundant containment spray system	$870k		$14k	$22k	$36k	$15k

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TABLE 7.3-1
MONETIZATION OF CPNPP UNITS 3 AND 4 US-APWR BASE CASE
INTERNAL EVENTS ONLY

Cost Component	Internal Events	Internal Fire	Internal Flood	LPSD	Totals for All Events
Off-site exposure cost	$4306	$6459	$5038	$719	$16,522
Off-site property damage cost	$7303	$10,955	$8545	$1220	$28,022
On-site exposure cost	$602	$903	$704	$101	$2311
Cleanup and decontamination cost	$18,367	$27,551	$21,489	$3067	$70,475
Replacement power cost	$73,689	$110,534	$86,216	$12,306	$282,744
Total (maximum averted cost)	$104,267	$156,401	$121,992	$17,413	$400,073

Base case is 7% discount rate.

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Total Value of Risk Averted

Value	Internal Events	Internal Fire	Internal Flood	LPSD	Total
CDF (per RY)[a]	1.2E-06	1.8E-06	1.4E-06	2.0E-07	4.6E-06
CPNPP, 7% Discount Rate	$104,267	$156,401	$121,992	$17,413	$400,073
CPNPP, 3% Discount Rate	$274,852	$412,278	$321,577	$45,900	$1,054,607

a) Core damage frequency values are from Table 5 of the DC Applicant's Environmental Report (MHI 2007).

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Insights from SAMA evaluations for license renewal

- Considerations:
  - CDFs from operating plants are relatively low
  - Past programs have addressed known weaknesses
  - SAMAs typically only act on one contributor, while risk is generally driven by multiple contributors
  - Implementation costs are high for design retrofits
  - Residual risk for advanced reactors is very low
- Therefore,
  - It is difficult to identify additional changes that substantially reduce risk and are cost-beneficial
  - Cost-beneficial changes usually limited to procedural changes and limited hardware changes
  - Averted onsite costs are important –promote preventative SAMAs

Insights from New Reactor SAMDA evaluations

- The new designs include severe accident prevention and mitigation features not found in first-generation plants. These address issues raised by the Commission that must be resolved in the design.
- Therefore, the overall severe accident risk is already significantly lowered and it is difficult to identify additional cost-effective design features.
- Some potential exists for impacts arising from adopting design departures and from site-specific external events.