Attachment E

Severe Accident Mitigation Alternatives Analysis

Attachment E contains the following sections:

- E.1 – Melcor Accident Consequences Code System Modeling
- E.2 – Evaluation of SAMA Candidates

E.1 MELCOR ACCIDENT CONSEQUENCES CODE SYSTEM MODELING

E.1.1 Introduction

The following sections describe the assumptions made and the results of modeling performed to assess the risks and consequences of severe accidents at ANO-2.

The severe accident consequence analysis was carried out with the Melcor Accident Consequence Code System (Reference E.1-1). MACCS2 simulates the impact of severe accidents at nuclear power plants on the surrounding environment. The principal phenomena considered in MACCS2 are atmospheric transport, mitigating actions based on dose projection, dose accumulation by a number of pathways including food and water ingestion, early and latent health effects, and economic costs.

E.1.2 Input

The input data required by MACCS2 are outlined below.

E.1.2.1 Core Inventory

The core inventory in Table E.1-1 is for ANO-2 at a power level of 3026 megawatts-thermal (Reference E.1-11). These values were obtained by adjusting the end-of-cycle values for a 3,412 megawatts-thermal pressurized water reactor by a linear scaling factor of 0.887 (Reference E.1-1).

E.1.2.2 Source Terms

The source term input data to MACCS2 were the severe accident source terms presented in the probabilistic risk assessment in the ANO-2 IPE (Reference E.1-2). This document defines the releases in terms of release modes and demonstrates the method of calculating releases. There are 51 release modes: 20 with early containment failure, 25 with late containment failure, and 6 with containment bypass as the failure mode. Table E.1-2 lists the input release fractions for each MACCS2 nuclide group together with the source category frequencies calculated in the probabilistic risk assessment. For all modes the Ruthenium, Lanthanum, Cerium, and Barium fractions of the usual MACCS2 species were set to zero, as they were not reported in the IPE submittal. Assignment of the radionuclides in Table E.1-1 to these nuclide groups was the same as that of the standard MACCS2 input. Other related source term data, such as release durations and energies, were evaluated by comparison with similar releases reported in the NUREG-1150 studies for the Surry plant (Reference E.1-3).

The amount of each radionuclide released to the atmosphere for each accident sequence or release category was obtained by multiplying the core inventory at the time of the hypothetical accident (Table E.1-1) by the release fraction (Table E.1-2) assigned to each of the nuclide groups.

The off-site consequences were summed for the release modes weighted by the annual frequency to obtain the total annual accident risk for the baseline and for each of the SAMA candidates evaluated. (This summation calculation was performed outside of the MACCS2 code as part of the SAMA cost benefit analyses.)

E.1.2.3 Meteorological Data

The MACCS2 input included a full year (1996) of consecutive hourly values of wind speed, wind direction and stability class recorded at the site meteorological tower. Since the site did not record precipitation data for 1996, precipitation data was obtained for the nearest available recording site from the National Climatic Data Center of the National Oceanic and Atmospheric Administration of the U.S. Dept. of Commerce. This was the hourly precipitation recorded for 1996 at Clarksville 6 NE COOP STATION 03157, located at 35º 32' N, 93º 24' W (about 20 miles northwest of the ANO-2 site) (Reference E.1-4). The seasonal mixing heights for this area of Arkansas were taken from maps of mixing heights for the United States.

This weather data is representative and typical for the following reasons:

(a) The population density is relatively low near the plant. This, together with the weather sampling scheme used by MACCS2, tends to diminish the importance of year-to-year meteorological variations, and

(b) The SAMA analysis is concerned with differences, subtracting the SAMA effect from the baseline effect. Because of this differential approach, the effect of year-to-year weather variations on differential benefits is of second order importance, and does not significantly affect the results.

MACCS2 calculations examine a representative subset of the 8,760 hourly observations contained in one year's data set (typically about 150 sequences). The representative subset is selected by sampling the weather sequences after sorting them into weather bins defined by wind speed, atmospheric stability, and rain conditions at various distances from the site.

E.1.2.4 Population Distribution

The predicted population around the site for the year 2040 was distributed by location in a grid consisting of sixteen directional sectors, the first of which is centered on due north, the second on 22.5 degrees east of north, and so on. A summary of the population distribution is shown in Table E.1-3. The direction sectors were divided into 15 radial intervals extending out to 50 miles. The habitable land fraction for each grid element was calculated from land fraction data within a 50-mile radius of the plant.

The basis for the extrapolated population data is the 2000 census (Reference E.1-10) and the estimated 1998 transient population. The census data was obtained from the University of Arkansas/Little Rock Institute for Economic Advancement (the official repository of the Arkansas census data). The data was processed by first determining if the center (centroid) of a census block occurred within a grid sub-sector. If so, the population associated with that census block was assigned to that particular sub-sector. Since the centroid for one of the census blocks occurs with 0.65 miles of the plant, this standard practice makes it appear that 28 people reside with the exclusion area boundary. Actually, no one resides with the exclusion area boundary, and this is just an artifact of the population distribution process, and is considered conservative.

Before extrapolation to 2040, the 2000 population was adjusted to account for transient population. The transient population in the emergency planning zone (exclusion boundary of 0.65 miles to 10 miles) was estimated and added to the resident population. The area is a popular recreational zone and it was considered appropriate to add these individuals for dose estimation purposes (even though it results in an overestimation of the economic costs for non-farm property in this area). A similar approach was used for the ANO-1 SAMA (Reference E.1-9). For the ANO-1 analysis, the number of cars into each recreational area was taken from the Site Emergency Plan. From this source, the number of individuals in each sub-sector was estimated for 1980. For the ANO-2 analysis, the ANO-1 estimates were extrapolated to 2000 by using the ratio of Arkansas population in 2000 to Arkansas population in 1980 as a scale factor.

The 2000 census data (Reference E.1-10) and the 1990 census data (Reference E.1-5) were then used to project the future rosette section populations for the year 2040. A 50-mile radius growth factor was calculated by dividing the 50-mile radius population in 2000 by the 1990 population. This resulted in a growth factor of 27.34% per decade. The section population projection for 2040 was then estimated by extrapolating the 2000 section population according to this growth factor.

Using the 2040 projected population yields conservative results, since a severe accident and radiological release can only occur between now and the end of the period of extended operation (2038). The population in 2038 is likely to be less than that projected for 2040. Since economic impact is a function of population, the actual economic impact would be less than the estimated economic impact.

Since the population projections include transient population estimates in the 10-mile zone around the plant, the data is slightly larger in this zone than may be shown elsewhere in tables of population projections for the region.

E.1.2.5 Emergency Response

The evacuation modeling employed for the severe accident mitigation alternatives analyses was based on the site-specific evacuation plan (Reference E.1-7). The plan addresses evacuation of the population within the plume exposure emergency planning zone, a 10-mile radius centered on the plant site.

The emergency evacuation model was modeled as a single radial evacuation zone extending out 10 miles from the plant. In the plan, it is stated that 15% of the people will start moving 30 minutes after the alarm rings, 80% of people will start moving 90 minutes after the alarm rings, and 5% of the people will start moving 120 minutes after the alarm rings. The clear times for each of the four emergency planning zones were estimated by using weighted averages of the plan clear times for four different time periods, weekday, night, weekend, and adverse weekday. The average evacuation speed for the emergency zone was then estimated using the population-weighted average of the evacuation speed of each planning zone.

Because of the recreational nature of the area immediately surrounding the plant, the population in the emergency zone was augmented by adding the transient population to the census-based resident population. An average evacuation start time delay of 4950 seconds and an average radial evacuation speed of 1.2 m/s were estimated in the above manner. Due to the uncertainty of the population proportionality assumption, the value of 1.0 m/s (used in the ANO-1 SAMA analysis, Reference E.1-9) was used for the evacuation speed. A sensitivity analysis using the 1.2 m/s evacuation speed showed a drop of almost 9% in the population dose, demonstrating that the base case parameter generates conservative results.

For this analysis it was conservatively assumed that people beyond 10 miles would continue their normal activities unless the following predicted radiation dose levels are exceeded. At locations for which 50 rem whole body effective dose equivalent in one week is predicted, it was assumed that relocation would take place after half a day. If 25 rem whole body dose equivalent in one week is predicted, relocation of individuals in those sectors was assumed to take place after one day.

A sensitivity analysis was performed in which it was assumed that only 90% of the people within the emergency planning zone participated in the evacuation. The remaining 10% were assumed to be unable or unwilling to evacuate and were assumed to go about their normal activities. The results were not significantly different from the complete evacuation case. While the population doses increased and the evacuation costs decreased, the overall population exposure and accident mitigation costs are governed mainly by the long term effects over the whole 50-mile zone, and so the net changes were small.

Another sensitivity analysis was performed to assess the importance of the warning and release delay times. Two hours were subtracted from the base case alarm and delay times, while the late release start time was decreased from 150,000 seconds to 86,400 seconds to effect a comparable change. The results show that the duration has a small impact on the overall population dose since evacuees spend more time in the last phase of evacuation when there are more mechanisms for sheltering. The results demonstrate that the base case parameters generate conservative results.

The long-term phase was assumed to begin after one week and extend for five years. Long-term relocation was assumed to be triggered by a 4 rem whole body effective dose equivalent. Long-term protective measures were assumed to be based on generic protective action guideline levels for actions such as decontamination, temporary relocation, contaminated crops, and milk condemnation, and farmland production prohibition.

E.1.2.6 Economic Data

Land use statistics including farmland values, farm product values, dairy production, and growing season information were provided on a countywide basis within 50 miles.

The values used for these parameters were the same as those used for the ANO-1 analysis (Reference E.1-9). This data was taken from the computer program SECPOP90 (Reference E.1-5), which contains a database extracted from Bureau of the Census PL 94-171 (block level census) CD-ROMS (Reference E.1-6), the 1992 Census of Agriculture CD ROM Series 1B, the

1994 U.S. Census County and City Data Book CD-ROM, the 1993 and 1994 Statistical Abstract of the United States, and other minor sources. The reference contains details on how the database was created and checked. The regional economic values were updated to 2002 using the consumer price indices for 1997 and 2002 (Reference E.1-8).

Economic consequences were estimated by summing the following costs:

- Costs of evacuation,
- Costs for temporary relocation (food, lodging, lost income),
- Costs of decontaminating land and buildings,
- Lost return-on-investments from properties that are temporarily interdicted to allow contamination to be decreased by decay of nuclides,
- Costs of repairing temporarily interdicted property,
- Value of crops destroyed or not grown because they were contaminated by direct deposition or would be contaminated by root uptake, and
- Value of farmland and of individual, public, and non-farm commercial property that is condemned.

Table E.1-4 lists the values of the economic parameters used in MACCS2.

Costs associated with damage to the reactor, the purchase of replacement power, medical care, life-shortening, and litigation are not estimated by MACCS2.

E.1.3 Results

Using the preceding input data, MACCS2 was used to estimate the following:

- The downwind transport, dispersion, and deposition of the radioactive materials released to the atmosphere from the failed reactor containment.
- The short-term and long-term radiation doses received by exposed populations via direct (cloud shine, plume inhalation, ground shine, and re-suspension inhalation) and indirect (ingestion) pathways.
- The mitigation of those doses by protective actions (evacuation, sheltering, and post-accident relocation of people; disposal of milk, meat, and crops; and decontamination, temporary interdiction, or condemnation of land and buildings).

- The early fatalities and injuries expected to occur within one year of the accident (early health effects) and the delayed (latent) cancer fatalities and injuries expected to occur over the lifetime of the exposed individuals.

- The off-site costs of short-term emergency response actions (evacuation, sheltering, and relocation), of crop and milk disposal, and of the decontamination, temporary interdiction, or condemnation of land and buildings.

The consequences estimated with the MACCS2 model in terms of the population dose and off-site economic costs for the base case are shown in Table E.1-5. These factors were used to estimate risk by multiplying the frequencies by the consequences. The resultant risk was then expressed as the magnitude of consequences expected per unit time. Table E.1-6 shows the risk measures for the base case and the three evacuation-model sensitivity cases (1.2 m/s evacuation speed, 90% evacuation and 2 hour shorter duration). These were obtained by summing the frequencies multiplied by the consequences over the entire range of distributions. Because the probabilities are on a per reactor-year basis, the averages shown are also on a per reactor-year basis.

Table E.1-1, ANO-2 Core Inventory [1]

Nuclide	Core inventory (becquerels)	Nuclide	Core inventory (becquerels)
Cobalt-58	2.86E+16	Tellurium-131M	4.15E+17
Cobalt-60	2.19E+16	Tellurium-132	4.13E+18
Krypton-85	2.20E+16	Iodine-131	2.84E+18
Krypton-85M	1.03E+18	Iodine-132	4.19E+18
Krypton-87	1.88E+18	Iodine-133	6.01E+18
Krypton-88	2.54E+18	Iodine-134	6.60E+18
Rubidium-86	1.67E+15	Iodine-135	5.67E+18
Strontium-89	3.18E+18	Xenon-133	6.02E+18
Strontium-90	1.72E+17	Xenon-135	1.13E+18
Strontium-91	4.09E+18	Cesium-134	3.84E+17
Strontium-92	4.26E+18	Cesium-136	1.17E+17
Yttrium-90	1.84E+17	Cesium-137	2.14E+17
Yttrium-91	3.88E+18	Barium-139	5.57E+18
Yttrium-92	4.28E+18	Barium-140	5.51E+18
Yttrium-93	4.84E+18	Lanthanum-140	5.63E+18
Zirconium-95	4.90E+18	Lanthanum-141	5.17E+18
Zirconium-97	5.11E+18	Lanthanum-142	4.98E+18
Niobium-95	4.63E+18	Cerium-141	5.01E+18
Molybdium-99	5.41E+18	Cerium-143	4.87E+18
Technetium-99M	4.67E+18	Cerium-144	3.02E+18
Ruthenium-103	4.03E+18	Praseodymium-143	4.79E+18
Ruthenium-105	2.62E+18	Neodymium-147	2.14E+18
Ruthenium-106	9.15E+17	Neptunium-239	5.73E+19
Rhodium-105	1.81E+18	Plutonium-238	3.25E+15
Antimony-127	2.47E+17	Plutonium-239	7.33E+14
Antimony-129	8.76E+17	Plutonium-240	9.24E+14
Tellurium-127	2.39E+17	Plutonium-241	1.56E+17
Tellurium-127M	3.16E+16	Americium-241	1.03E+14
Tellurium-129	8.22E+17	Curium-242	3.93E+16
Tellurium-129M	2.17E+17	Curium-244	2.30E+15

[1] Reference E.1-1.

Table E.1-2, ANO-2 RELEASE FRACTION BY NUCLIDE GROUP [2]

Release Mode [3]	Frequency [4]	Xenon/ Krypton	Iodine	Cesium	Tellurium	Strontium
A1	4.22E-08	9.20E-01	1.07E-04	9.02E-05	2.99E-05	4.17E-07
A2	8.73E-10	9.20E-01	4.29E-03	3.61E-03	1.20E-03	1.67E-05
B1	1.46E-13	9.20E-01	2.64E-04	2.15E-04	5.99E-05	8.35E-07
B2-L	7.48E-11	9.20E-01	9.96E-03	8.18E-03	2.40E-03	3.34E-05
B2-R	3.95E-12	9.20E-01	9.96E-03	8.18E-03	2.40E-03	3.34E-05
B3-L	7.06E-10	9.20E-01	2.64E-04	2.15E-04	5.99E-05	8.35E-07
B3-R	7.06E-10	9.20E-01	2.64E-04	2.15E-04	5.99E-05	8.35E-07
B4-L	7.32E-09	9.20E-01	9.96E-03	8.18E-03	2.40E-03	3.34E-05
B4-R	1.05E-09	9.20E-01	9.96E-03	8.18E-03	2.40E-03	3.34E-05
B5-L	7.06E-10	9.20E-01	8.82E-04	4.76E-04	1.13E-04	1.57E-06
B5-R	7.06E-10	9.20E-01	8.82E-04	4.76E-04	1.13E-04	1.57E-06
B6-L	3.19E-07	9.20E-01	4.04E-03	2.29E-03	2.03E-04	2.83E-06
B6-R	1.74E-08	9.20E-01	4.04E-03	2.29E-03	2.03E-04	2.83E-06
BP-D3A	3.57E-08	7.44E-01	2.10E-02	2.13E-02	1.51E-02	1.38E-04
BP-D3B	3.57E-08	9.20E-01	2.18E-01	2.21E-01	5.86E-02	1.14E-03
BP-E5A	8.96E-09	8.24E-01	2.12E-02	2.14E-02	1.54E-02	1.38E-04
BP-E5B	8.96E-09	1.00E+00	2.23E-01	2.26E-01	6.56E-02	1.14E-03
BP-E6A	2.98E-09	8.24E-01	2.84E-02	2.60E-02	2.43E-02	1.42E-04
BP-E6B	3.30E-07	1.00E+00	3.89E-01	3.43E-01	2.58E-01	1.16E-03
C1-L	4.71E-09	1.00E+00	6.39E-04	4.85E-04	1.06E-03	8.35E-07
C1-R	9.16E-10	1.00E+00	6.39E-04	4.85E-04	1.06E-03	8.35E-07
C2-L	8.74E-10	1.00E+00	1.03E-02	8.45E-03	4.26E-03	3.34E-05
C2-R	7.13E-10	1.00E+00	1.03E-02	8.45E-03	4.26E-03	3.34E-05
C3-L	3.13E-06	1.00E+00	6.65E-04	5.04E-04	1.06E-03	8.35E-07
C3-R	1.66E-07	1.00E+00	6.65E-04	5.04E-04	1.06E-03	8.35E-07
C4-L	5.46E-07	1.00E+00	2.12E-02	1.63E-02	3.03E-02	3.34E-05
C4-R	2.94E-08	1.00E+00	2.12E-02	1.63E-02	3.03E-02	3.34E-05
C5-L	3.91E-07	1.00E+00	1.26E-03	7.46E-04	1.11E-03	1.57E-06
C5-R	2.12E-08	1.00E+00	1.26E-03	7.46E-04	1.11E-03	1.57E-06
C6-L	5.08E-07	1.00E+00	1.53E-02	1.04E-02	2.81E-02	2.83E-06

[2] Reference E.1-2.

[3] Release Modes notation:

A, B, C = late releases.
BP = bypass release modes
D, E = early releases
-R = containment rupture
-L = containment leak

[4] Release Mode frequency per reactor year.

Table E.1-2, ANO-2 RELEASE FRACTION BY NUCLIDE GROUP [2]

Release Mode [3]	Frequency [4]	Xenon/ Krypton	Iodine	Cesium	Tellurium	Strontium
C6-R	2.73E-08	1.00E+00	1.53E-02	1.04E-02	2.81E-02	2.83E-06
D1-L	1.61E-11	9.20E-01	1.41E-03	1.18E-03	3.81E-04	5.31E-06
D1-R	2.62E-09	9.20E-01	5.70E-03	4.79E-03	1.58E-03	2.20E-05
D2-L	3.10E-08	9.20E-01	5.60E-02	4.69E-02	1.52E-02	2.13E-04
D2-R	3.20E-08	9.20E-01	2.28E-01	1.91E-01	6.32E-02	8.80E-04
D3-L	3.49E-08	9.20E-01	5.11E-03	2.73E-03	7.19E-04	1.00E-05
D3-R	5.47E-08	9.41E-01	5.62E-02	3.66E-02	2.36E-02	3.41E-03
D4-L	1.36E-06	9.41E-01	2.02E-02	1.25E-02	6.27E-03	8.30E-04
D4-R	1.36E-06	9.41E-01	7.54E-02	4.70E-02	2.60E-02	3.44E-03
E1-L	7.06E-10	1.00E+00	2.66E-03	2.08E-03	2.73E-03	5.31E-06
E1-R	7.06E-10	1.00E+00	1.10E-02	8.57E-03	8.61E-03	2.20E-05
E2-L	1.04E-09	1.00E+00	5.72E-02	4.78E-02	1.90E-02	2.13E-04
E2-R	1.12E-09	1.00E+00	2.33E-01	1.95E-01	7.63E-02	8.80E-04
E3-L	9.60E-10	1.00E+00	2.75E-03	2.15E-03	2.37E-03	5.31E-06
E3-R	4.19E-08	1.00E+00	1.13E-02	8.84E-03	8.61E-03	2.20E-05
E4-L	2.41E-07	1.00E+00	9.35E-02	7.39E-02	7.11E-02	2.13E-04
E4-R	2.56E-07	1.00E+00	3.85E-01	3.05E-01	2.60E-01	8.80E-04
E5-L	9.36E-09	1.00E+00	6.36E-03	3.63E-03	2.71E-03	1.00E-05
E5-R	1.44E-08	1.00E+00	6.01E-02	3.94E-02	2.87E-02	3.41E-03
E6-L	5.15E-07	1.00E+00	4.77E-02	3.23E-02	4.73E-02	8.30E-04
E6-R	5.19E-07	1.00E+00	1.91E-01	1.30E-01	1.71E-01	3.44E-03

[2] Reference E.1-2.

[3] Release Modes notation:

A, B, C = late releases.
BP = bypass release modes
D, E = early releases
-R = containment rupture
-L = containment leak

[4] Release Mode frequency per reactor year.

Table E.1-3
ANO-2 Regional Population Distribution
(With Emergency Zone Transient Population)

	0-10 Miles	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles	Totals
N	2318	1341	216	2020	9045	14940
NNE	1999	3311	216	1352	3130	10008
NE	5954	5709	460	2099	4353	18575
ENE	7909	6843	3159	2922	16774	37607
E	15451	9250	4773	9121	28912	67507
ESE	57546	16111	17261	20780	135403	247101
SE	15779	2635	3643	11593	8724	42374
SSE	9913	3667	2751	134	31836	48301
S	7514	7409	3653	421	5092	24089
SSW	3903	6183	5975	673	1999	18733
SW	1146	2838	3251	1483	1231	9949
WSW	986	604	2204	10154	14441	28389
W	940	4918	15688	10391	16246	48183
WNW	4044	4570	10964	22413	10415	52406
NW	5509	29238	5975	1767	3472	45961
NNW	2235	3485	1644	1255	2435	11054
Totals	143146	108112	81833	98578	293508	725177

Table E.1-4, MACCS2 Economic Parameters

Variable	Description	Value
DPRATE	Property depreciation rate (per yr)	0.2
DSRATE	Investment rate of return (per yr)	0.12
EVACST	Daily cost for a person who has been evacuated ($/person-day)	43.05
POPCST	Population relocation cost ($/person)	7967.12
RELCST	Daily cost for a person who is relocated ($/person-day)	43.05
CDFRM0	Cost of farm decontamination for various levels of decontamination ($/hectare)	896.59 1992.49
CDNFRM	Cost of non-farm decontamination per resident person for various levels of decontamination ($/person)	4781.42 12754.28
DLBCST	Average cost of decontamination labor ($/man-year)	55792.80
VALWF0	Value of farm wealth ($/hectare)	4547.23
VALWNF	Value of non-farm wealth ($/person)	126107.80

Table E.1-5, Summary of Off-site Consequence Results for Each Release Category

Table E.1-5		
Release Category	**Population Dose (Sieverts)**	**Total Economic Cost (Dollars)**
A1	250	1.07E+07
A2	2410	3.56E+08
B1	494	2.53E+07
B2-L	3630	6.47E+08
B2-R	3630	6.47E+08
B3-L	494	2.53E+07
B3-R	494	2.53E+07
B4-L	3630	6.47E+08
B4-R	3630	6.47E+08
B5-L	827	6.96E+07
B5-R	827	6.96E+07
B6-L	1890	2.67E+08
B6-R	1890	2.67E+08
BP-D3A	5150	1.18E+09
BP-D3B	12200	3.46E+09
BP-E5A	5180	1.18E+09
BP-E5B	12500	3.48E+09
BP-E6A	5700	1.35E+09
BP-E6B	18900	3.93E+09
C1-L	862	6.96E+07
C1-R	862	6.96E+07
C2-L	3710	6.61E+08
C2-R	3710	6.61E+08
C3-L	888	7.05E+07
C3-R	888	7.05E+07
C4-L	5410	1.05E+09
C4-R	5410	1.05E+09

Table E.1-5		
Release Category	**Population Dose (Sieverts)**	**Total Economic Cost (Dollars)**
C5-L	1080	1.12E+08
C5-R	1080	1.12E+08
C6-L	4360	7.84E+08
C6-R	4360	7.84E+08
D1-L	1320	1.82E+08
D1-R	2480	4.51E+08
D2-L	7170	2.23E+09
D2-R	14400	3.31E+09
D3-L	2070	3.14E+08
D3-R	6960	1.77E+09
D4-L	4670	9.17E+08
D4-R	7990	1.97E+09
E1-L	1800	2.66E+08
E1-R	3630	6.41E+08
E2-L	7280	2.25E+09
E2-R	14700	3.34E+09
E3-L	1830	2.73E+08
E3-R	3670	6.53E+08
E4-L	8350	2.82E+09
E4-R	22800	3.82E+09
E5-L	2400	3.86E+08
E5-R	7270	1.84E+09
E6-L	6890	1.80E+09
E6-R	13700	3.02E+09

Table E.1-6, Risk Measures

	Population Dose (Rem)	Economic Cost ($)	Population Dose (% increase from base case)	Economic Cost (% increase from base case)
Base Case	1.723	3385	----	-----
1.2 m/s evacuation speed	1.568	3385	-9.0%	0.0%
90% evacuation	1.773	3364	2.8%	-0.6%
2 hour shorter duration	1.737	3394	0.81%	0.25%

E.1.4 References

E.1-1 *Code Manual for MACCS2, User's Guide*, D. Chanin and M. L. Young, Technadyne Engineering Consultants and Sandia National Laboratories for U. S. Nuclear Regulatory Commission and U. S. Department of Energy, SAND97-0594, NUREG/CR-6613, Vol. 1, May 1998.

See also,

MELCOR Accident Consequence Code System (MACCS), Model Description, H. N. Jow, et. al., Sandia National Laboratories for U. S. Nuclear Regulatory Commission, SAND86-1562, Vol. 2, NUREG/CR-4691, February 1990.

Evaluation of Severe Accident Risks: Quantification of Major Input Parameters, MACCS Input, J. L. Sprung, et. al., Sandia National Laboratories for the U. S. Nuclear Regulatory Commission, NUREG/CR-4551, Vol. 2, Rev. 1, Part 7, December 1990.

E.1-2 *ANO-2 Probabilistic Risk Assessment (PRA) Individual Plant Examination (IPE) Submittal*, Report Number 94-R-2005-01, March 1994.

E.1-3 *Evaluation of Severe Accident Risks: Surry 1 Main Report*, NUREG/CR-4551, Vol. 3, Rev. 1, Part 1, Breeding, R. J., et al, October 1990.

E.1-4 *1996 Hourly Precipitation Data for Clarksville 6 NE COOP ID 031457*, NCDC (National Climatic Data Center, National Oceanic and Atmospheric Administration), Order Num. 6394, May 7, 1999.

E.1-5 *SECPOP90: Sector Population, Land Fraction, and Economic Estimation Program,* NUREG/CR-6525, Humphreys, S. L., et al, September, 1997.

E.1-6 *Census of Population and Housing, 1990: Public Law (P. L.) 94-171, Data Technical Documentation*, CD – ROM set, BOC (Bureau of the Census, U. S. Dept. of Commerce), 1991.

E.1-7 *ANO Emergency Plan*, Entergy Operations, Inc., Rev. 28, January 15, 2003.

E.1-8 *Bureau of Labor Statistics - Consumer Price Index*, www.bls.gov/cpi.

E.1-9 *Safety Evaluation Report Related to the License Renewal of Arkansas Nuclear One, Unit 1*, NUREG-1743, April 2001.

E.1-10 *Arkansas Nuclear One 2000 Census Data*, letter from B. West, FTN Associates, Ltd. To R. Buckley, Entergy Services, Inc., FTN 6045-062, February 5, 2003.

E.1-11 *Arkansas Nuclear One, Unit No. 2 – Issuance of Amendment RE: Increase in Licensed Power Level (Tac. No. MB0789)*, letter from T. W. Alexion to C. G. Anderson, 2CNA040207, April 24, 2002.

E.2 EVALUATION OF SAMA CANDIDATES

This section describes the generation of the initial list of potential SAMA candidates, screening methods, and the analysis of the remaining SAMA candidates.

E.2.1 SAMA List Compilation

A list of SAMA candidates was developed by reviewing industry documents and considering plant-specific enhancements not identified in published industry documents. Since ANO-2 is a conventional Combustion Engineering nuclear power reactor, considerable attention was paid to the SAMA candidates from SAMA analyses for other CE plants. Attention was also paid to the generation and screening of plant-specific enhancements documented in the ANO-1 SAMA evaluation. Industry documents reviewed include the following:

Calvert Cliffs Nuclear Power Plant SAMA Analysis (Reference E.2-1)

Combustion Engineering System 80+ SAMDA Analysis (Reference E.2-2)

Arkansas Nuclear One Unit 1 SAMA Evaluation (Reference E.2-3)

The above documents represent a compilation of SAMA candidates developed from other industry documents. These sources of industry documents include:

Watts Bar Nuclear Plant Unit 1 PRA/IPE submittal

Limerick SAMDA cost estimate report

NUREG-1437 description of Limerick SAMDA

NUREG-1437 description of Comanche Peak SAMDA

Watts Bar SAMDA submittal

TVA response to NRC's RAI on the Watts Bar SAMDA submittal

Westinghouse AP600 SAMDA

Safety Assessment Consulting presentation by Wolfgang Werner at the NUREG-1560 conference

NRC IPE Workshop – NUREG-1560 NRC Presentation

NUREG-0498, Supplement 1, Section 7

NUREG/CR-5567, PWR Dry Containment Issue Characterization

NUREG-1560, Volume 2, NRC Perspectives on the IPE Program

NUREG/CR-5630, PWR Dry Containment Parametric Studies

NUREG/CR-5575, Quantitative Analysis of Potential Improvements for the Dry PWR Containment

ICONE paper by C. W. Forsberg, et. al., on a core melt source reduction system

In addition to SAMA candidates from review of industry documents, additional SAMA candidates were obtained from plant-specific sources, such as the ANO-2 Individual Plant Examination (IPE) (Reference E.2-4) and Individual Plant Evaluation of External Events (IPEEE) (Reference E.2-5). In both the IPE and IPEEE, several enhancements related to severe accident design performance were recommended. These nineteen enhancements were included in the comprehensive list of SAMA candidates and are listed below.

SAMA Candidates Obtained from the IPE (Reference E.2-4)

CB-22 Provide procedural verification that the shutdown cooling system is secured during startup by local verification that the shutdown cooling suction line isolation valves are closed. This additional check would reduce the potential for an interfacing system LOCA to be introduced through this path due to inadvertent valve mis-positioning resulting from valve failure to stroke properly.

CB-23 Add a procedural requirement to close manual valve 2HPA-2 to ensure that failure of 2SV-8231-2 will not introduce a small containment leak path.

CB-24 The potential exists during a degraded power condition for an unisolated leak path to develop from the containment through the 2" vent header line to the waste gas surge tank (2T17) via valves 2CV-2400-2 and 2CV-2401-1. Should this path be open prior to a degraded power (loss of AC) condition, the degraded power procedure could be used to ensure that these valves are closed, and to manually close 2CV-2401-1 or manual valve 2CVH-8, which is in series with these valves. This SAMA would increase the probability of successful containment isolation when required.

CB-25 Reorient 2CV-5254-2 to oppose potential flow from the reactor coolant system to reduce the potential of an interfacing system LOCA through a ruptured reactor coolant pump seal cooler tube. Increase component cooling water relief capacity to minimize the likelihood of the component cooling water piping breaking between 2CV-5255-1 and the containment penetration.

CW-23 Enhance loss of service water procedures to improve the ability to avoid unnecessary low pressure safety injection and containment spray pump overheating failures that can minimize the benefit of restoring service water.

EV-31 Remove check valve internals to improve the potential for cooling communication between molten core debris in the bottom of the cavity and water on the containment floor. Improved cooling of a failed core would decrease the potential for a post severe accident off-site release.

FW-17 Enhance emergency operating procedures to place emergency feedwater flow control valves in an open position once it has been determined that main steam isolation signal conditions do not exist. If the outboard flow control valves from both the motor-driven and turbine-driven pumps were in a full open position upon loss of power supply, the potential for loss of flow to both steam generators would be minimized.

OT-09 Flood fuel transfer tube in the event of core damage. This would reduce the potential for a high-temperature induced failure of the fuel transfer tube flange seals during accidents involving high pressure melt ejection. This action would help cool the transfer tube flange and its seals and would help scrub fission products escaping through failed seals.

SAMA Candidates Obtained from the IPEEE (Reference E.2-5)

IPEEE-01 Bolt control cabinets 2C02, 2C03, 2C04, 2C09, 2C16, 2C17, 2C21, 2C21-1, 2C22, and 2C23 together.

IPEEE-02 Ensure that the doors to cabinet 2C21-2 latch properly.

IPEEE-03 Connect back-to-back motor control centers 2B-54 & 2B-64 so they respond together during an earthquake.

IPEEE-04 Inspect the rear anchorage of 480V load centers.

IPEEE-05 Provide an additional anchorage for control cabinet 2C80.

IPEEE-06 Ensure the protection of control cabinet 2C80 during a seismic event. Control cabinet 2C80 has an adjacent instrumentation cabinet that could topple during an earthquake. Additionally, a fire extinguisher is nearby on a fairly short hook that could fall and become a potential missile.

IPEEE-07 Move breaker adjustment cranks from 480V load centers 2B-5 & 2B-6.

IPEEE-08 Close open S-hooks on light fixtures above motor control centers 2B-51 & 2B-61.

IPEEE-09 Further investigate the calculated value for high confidence low probability of failure (<0.3g) for the emergency diesel fuel tanks 2T-57A & 2T-57B.

IPEEE-10 Tighten doors of control cabinet 2C-16 so they do not rattle during an earth quake.

IPEEE-11 Further investigate the calculated value for high confidence low probability of failure (<0.3g) for inverters 2A-3 and 2A-4.

The current ANO-2 PSA model was also used to identify plant-specific modifications for inclusion in the comprehensive list of SAMA candidates. The top 100 cut sets from the PSA model were reviewed for patterns that could be addressed through a potential enhancement to the plant. Sixteen postulated modifications were developed, included in the list of SAMA candidates, and listed below.

SAMA Candidates Obtained from the Current PSA Model

AC/DC-24 Create the ability to automatically transfer battery charger/eliminator 2D31B to an alternate power source upon demand. This SAMA would reduce the potential for human error in transferring battery charger 2D31B to an alternate power source.

CB-26 Change plant operating procedures to isolate the low pressure safety injection line following the failure of series system check valves. Also, enhance operator training on coping with interfacing system LOCAs resulting from reactor coolant pump seal cooler tube ruptures.

CC-18 Prevent plugging of the containment sump strainers by modifying the existing strainers and adding additional strainer area.

CC-19 Provide an additional flow path from the refueling water tank to the high-pressure safety injection system through a diversified suction flow path check valve. This SAMA would reduce the potential for common cause failure of refueling water tank flow path check valves.

CC-20 Replacing either containment sump valve 2CV-5649-1 or 2CV-5650-2 with an air-operated valve. This would reduce the potential for common cause failure of these valves preventing adequate core cooling.

CC-21 Reduce the potential for common cause failure of high-pressure safety injection motor-operated valves by replacing redundant train valve actuators with diversified valve actuators.

CC-22 Reduce the potential of common cause failure of two or more recirculation actuation signal and engineered safety features actuation signal actuation relays (e.g., K104A/B, SSR-1/3A, etc.) This modification would replace existing relays with relays of a diverse design.

CC-23 Increase the reliability of automatic recirculation swap over. This modification would install an additional level transmitter and change the recirculation actuation logic from 2-out-of-4 to 2-out-of-5.

CC-24 Provide a bypass flow path with a normally open motor-operated control valve around the safety injection tank discharge control valves. This modification would increase the probability of injection if the motor-operated control valves fail closed.

CW-09 Provide an additional diversified service water pump. Decrease the frequency of core damage due to a loss of service water by installing an additional service water pump with an independent diesel generator. This modification also requires that one of the remaining service water pumps be supplied with an independent diesel to reduce the potential for common cause failure of all of the service water pumps.

CW-24 Provide the ability to automatically trip the reactor coolant pumps on a loss of component cooling water. This SAMA would reduce the potential for a seal LOCA following a loss of component cooling water by reducing the reliance on operator action to trip the reactor coolant pumps.

CW-25 Add a redundant valve in series with 2CV-1530-1 on service water header 1 (and 2CV-1531-2 on service water header 2). This SAMA would increase the reliability of isolation if the isolation valves supplying the component cooling water heat exchangers and main chillers fail to close upon demand.

CW-26 Reduce the failure frequency of the service water system. This SAMA would increase the inspection and cleaning frequency of the service water pump discharge filters, reducing the probability of a common cause failure.

CW-27 Reduce the failure frequency of the service water system. This SAMA would install backwash filters in place of the existing strainers, reducing the probability of a common cause failure.

EV-30 Reduce the potential for common cause failure of containment spray system motor-operated valves by replacing redundant train motor-operated valve actuators with diverse valve actuators.

FW-19 Create the ability to automatically align emergency feedwater/auxiliary feedwater suction to the other condensate storage tank on low-low level of 2T-41A or 2T-41B. This modification would reduce the potential for a loss of feedwater.

The comprehensive list contained a total of 192 SAMA candidates.

E.2.2 <u>Qualitative Screening of SAMA Candidates</u>

The purpose of the preliminary SAMA screening was to eliminate from further consideration enhancements that were not viable for implementation at ANO-2. Potential SAMA candidates were screened out if they modified features not applicable to ANO-2, if they had already been implemented at ANO-2, or if they were similar in nature and could be combined with another SAMA candidate to develop a more comprehensive or plant-specific SAMA candidate.

During this process, 99 of the 192 original SAMA candidates were eliminated, leaving 93 SAMA candidates for further analysis. These 93 improvements are listed in Table E.2-1.

The final screening process involved identifying and eliminating those items whose cost exceeded their benefit as described below. Table E.2-1 provides a description of each of the 93 SAMA candidates.

E.2.3 Final Screening of SAMA Candidates

A benefits analysis was performed on each of the remaining SAMA candidates. The benefit was defined as the sum of the dollar equivalents for each severe accident impact (off-site exposure, off-site economic costs, occupational exposure, and on-site economic costs). If the expected cost exceeded the estimated benefit, the SAMA was not considered cost-beneficial.

Implementation of each SAMA candidate would change the severe accident risk (i.e., a change in frequency or consequence of severe accidents). Bounding evaluations (or analysis cases) were performed to address specific SAMA candidates or groups of similar SAMA candidates. These analysis cases overestimated the benefit and thus were conservative calculations. For example, one SAMA candidate suggested installing a digital large break LOCA protection system. The bounding calculation estimated the benefit of this improvement by total elimination of risk due to large break LOCAs (see analysis case LBLOCA, below). This calculation obviously overestimated the benefit, but if the inflated benefit indicated that the SAMA candidate was not cost-beneficial then the purpose of the analysis was satisfied. A description of the analysis cases used in the evaluation follows.

AIR

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the plant air compressors were replaced with a more reliable model. Although the proposed SAMA would not completely eliminate air compressor failures, a bounding benefit was estimated by setting the plant air compressor failure events to zero. Perfectly reliable air compressors result in minimal benefit. This analysis case was used to model the benefit of SAMA IA-02.

ATWS1

This analysis case was used to estimate the maximum attainable benefit from enhancements related to ATWS coping. For this case, the maximum attainable benefit of ATWS reduction was estimated by multiplying the results of the MAXBENEFIT case by the ratio of the CDF contribution of an ATWS to the total CDF, [(ATWS CDF)/ (Total CDF)*(MAXBENEFIT)]. The ATWS contribution to core damage is 1.59E-6. Elimination of core damage due to an ATWS results in a benefit of approximately $140,000. This analysis case was used to model the benefit of SAMAs AT-01, AT-02 and AT-03.

ATWS2

This analysis case was used to estimate the benefit associated with increasing the charging pump lube oil capacity. The benefit was obtained by multiplying the results of the MAXBENEFIT case by the ratio of the change in the CDF of an ATWS to the total CDF of ANO-2 (i.e., [{ΔATWS CDF/Total CDF}*{MAXBENEFIT}]). The ATWS contribution to core damage is

1.59E-6. The ATWS frequency is derived from three sequence groups: Turbine Trip (1.34E-6/yr), Loss of MFW (1.26E-7/yr), and LOOP (1.25E-7/yr). Examination of the ATWS cut sets (Reference E.2-7) indicates that for top event BW (borated water addition) following turbine trip/loss of MFW, 9.5% of the top event probability is from cut sets that include failure of at least one charging pump. For top event BW following a LOOP, 0.38% of the top event probability is from cut sets that include charging pump failure. To approximate the benefit from this SAMA, these percentages were applied to the ATWS sequence frequencies above. Hence, the revised ATWS CDF (1.45E-6) is an estimate of the fraction of the initial ATWS CDF not associated with charging pump failure. Therefore, the benefit associated with making the charging pumps perfectly reliable has an estimated value of $12,000. This analysis case was used to model the benefit of SAMA CW-07.

BRKR

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if procedures were enhanced to repair or change out failed 4160VAC breakers. Although the proposed SAMA would not eliminate all potential failures of the 4160VAC breakers, a bounding benefit was estimated by removing the 4160VAC breaker gates. Elimination of all 4160V breaker failures results in a benefit of approximately $6,000. This analysis case was used to model the benefit of SAMA AC/DC-15.

CAVITY

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if reactor cavity flooding ability was enhanced. Plant damage state IVKi is dominated by a sequence initiated by a transient event, followed by unsuccessful secondary cooling, successful once-through cooling during the injection mode and failure of HPSI during the recirculation mode as a result of high temperature containment sump water combined with high room temperature. Removal of the internals from check valve 2BS-46 was recommended in the ANO-2 IPE to mitigate this type of sequence. Although the proposed SAMAs would not completely eliminate the potential for such a scenario, a bounding benefit was estimated by removing all risk contribution attributable to this PDS. Elimination of core damage attributable to plant damage state IVKi results in a benefit of approximately $17,000. This analysis case was used to model the benefit of SAMAs EV-15, EV-16, EV-17, and EV-31.

CBPEN

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the station blackout procedure included a requirement to close manual valve 2HPA-2. PDS SBOu is composed of station blackout events with unsuccessful containment isolation. In this scenario, combinations of DC and AC power failures could result in failure of 2SV-8231-2 to close or remain closed. Removal of this PDS is the modeling equivalent of manually closing 2HPA-2, which was recommended in the ANO-2 IPE to ensure that failure of 2SV-8231-2 will not introduce a containment leak path. Although the proposed SAMA would not completely eliminate the potential for such a scenario, a bounding benefit was estimated by eliminating this PDS. Elimination of all core damage attributable to plant damage state SBOu results in a benefit of approximately $200. This analysis case was used to model the benefit of SAMA CB-23.

CST

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the ability to automatically align EFW/AFW suction to the alternate condensate storage tank was installed. Although the proposed SAMA would not completely eliminate the potential failures, a bounding benefit was estimated by removing the human failure event for suction alignment. Perfectly reliable re-alignment of EFW/AFW suction to the alternate condensate storage tank results in a benefit of approximately $10,000. This analysis case was used to model the benefit of SAMA FW-19.

DCPWR

This analysis case was used to evaluate plant modifications that would increase the availability of Class 1E DC power (e.g., increased battery capacity or the installation of a diesel-powered generator that would effectively increase battery capacity). Although the proposed SAMAs would not completely eliminate the potential failure, a bounding benefit was estimated by removing the battery discharge events and battery failure events. Station battery capacity of 24 hours results in a benefit of approximately $34,000. This analysis case was used to model the benefit of SAMAs AC/DC-04, AC/DC-05, AC/DC-10, AC/DC-12, and AC/DC-24.

EDGCOOL

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if a back-up source of EDG cooling was installed. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing EDG service water cooling gates. Perfectly reliable EDG cooling results in a benefit of approximately $20,000. This analysis case was used to model the benefit of SAMA AC/DC-19.

EFW

This analysis case was used to evaluate the change in the plant risk profile that would be achieved following modifications making EFW more reliable, such as installing an independent diesel for the condensate storage tank makeup pumps or switching EFW room cooling power to station batteries in a station blackout. Although none of the proposed changes would completely eliminate EFW failures, a bounding benefit was estimated by removing all EFW system failure gates. A perfectly reliable EFW system results in a benefit of approximately $104,000. This analysis case was used to model the benefit of SAMAs FW-13 and HV-05.

EFWCV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved by modifying procedures directing operators to open the emergency feedwater flow control valves to the steam generators following failure due to power supply or signal failure.

Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by setting the corresponding human failure event to zero. Elimination of operator failure to open the emergency feedwater flow control valves results in a benefit of approximately $17,000. This analysis case was used to model the benefit of SAMA FW-17.

ESFASRELAY

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the engineered safety features actuation system actuation and solid state relays were replaced with diverse designs. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by eliminating the ESFAS actuation relay common cause failure events. Elimination of all core damage due to common cause failure of engineered safety features actuation and solid state relays results in a benefit of approximately $15,000. This analysis case was used to model the benefit of SAMA CC-22.

FDW

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if a digital feedwater upgrade was installed or modifications were made to cap the downstream piping of normally closed CCW drain and vent valves. Although none of the proposed changes would completely eliminate MFW failures, a bounding benefit was estimated by removing the loss of feedwater initiating event and MFW failure gates. Elimination of all core damage due to loss of feedwater results in a benefit of approximately $112,000. This analysis case was used to model the benefit of SAMA CW-01 and FW-01.

FILTER

This analysis case was used to evaluate the change in the plant risk profile that would be achieved by increasing the inspection frequency of the service water pump discharge filters or replacing them with backwash filters. Although none of the proposed changes would completely eliminate service water pump discharge filter failures, a bounding benefit was estimated by removing the service water pump discharge filter common cause failure event. Elimination of all common cause failures of service water pump discharge filters results in a benefit of approximately $100,000. This analysis case was used to model the benefit of SAMAs CW-26 and CW-27.

HPSICV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved by providing an additional flow path from the refueling water tank to the high pressure safety injection system. Although the proposed SAMA would not completely eliminate the potential failure, a bounding benefit was estimated by removing the HPSI system check valve failure events. Elimination of all core damage due to failure of the high-pressure safety injection flow path check valves results in a benefit of approximately $29,000. This analysis case was used to model the benefit of SAMA CC-19.

HPSIMOV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved by providing actuator diversity for the MOVs in the HPSI system. Although the proposed SAMA would not completely eliminate this potential failure, a bounding benefit was estimated by removing the HPSI MOV common cause failure event. Elimination of all core damage due to common cause failure of the high-pressure safety injection valves results in a benefit of approximately $22,000. This analysis case was used to model the benefit of SAMA CC-21.

HVAC

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if procedures were developed for temporary HVAC. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing the shutdown heat exchanger room cooling failure gates. Perfectly reliable shutdown heat exchanger room cooling results in a benefit of approximately $174,000. This analysis case was used to model the benefit of SAMAs HV-03.

ISLOCA

This analysis case was used to evaluate the change in the plant risk profile that would be achieved by reducing the probability or consequences of an ISLOCA event. Although none of the proposed changes would completely eliminate the occurrence or impact of ISLOCA events, a bounding benefit was estimated by removing the ISLOCA event. Elimination of all core damage from ISLOCA results in a benefit of approximately $86,000. This analysis case was used to model the benefit of SAMAs CB-13, CB-14, CB-19, and CB-20.

ISLOCAHEP

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if procedures, associated with operation and maintenance of systems interfacing the reactor coolant system, were enhanced. Although the proposed SAMA would not completely eliminate the potential for human failures, a bounding benefit was estimated by assuming perfect human reliability in the operation and maintenance of the systems interfacing the RCS. Elimination of all human error associated with an interfacing system LOCA results in a benefit of approximately $64,000. This analysis case was used to model the benefit of SAMA CB-26.

LBLOCA

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if a digital large break LOCA (LBLOCA) protection system was installed. Although the proposed change would not completely eliminate the potential for a LBLOCA, a bounding benefit was estimated by removing the LBLOCA initiating event. Elimination of all core damage due to large LOCAs results in a benefit of approximately $24,000. This analysis case was used to model the benefit of SAMA OT-07.

LOCCW

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the ability to cool the shutdown cooling heat exchangers was improved or an additional CCW pump was installed. Although the proposed SAMAs would not completely eliminate the potential for a loss of component cooling water, a bounding benefit was estimated by removing the component cooling water header failure gates. Elimination of all core damage due to loss of the component cooling water system results in a benefit of approximately $76,000. This analysis case was used to model the benefit of SAMAs CW-15 and CW-22.

LOOP

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the reliability of the Class 1E power distribution system was improved. Although none of the proposed changes would reduce the LOOP frequency to zero, a bounding benefit was estimated by removing the LOOP initiating event. Elimination of all loss of off-site power initiators results in a benefit of approximately $39,000. This analysis case was used to model the benefit of SAMAs AC/DC-02, AC/DC-09, AC/DC-13, AC/DC-20, AC/DC-21, and AC/DC-22.

LOOPREC

This analysis case was used to evaluate the change in the plant risk profile which would be achieved if the plant recovery steps following a station blackout were emphasized through enhanced training and procedural guidance. Although the proposed SAMA would not ensure instantaneous recovery of on-site equipment during a LOOP, a bounding benefit was estimated by removing events for LOOP non-recovery factors with one or more run failures.

It is difficult to separate the human element from the equipment failure element in the loss of off-site power recovery model. These particular recoveries are used for those cut sets that involved convolution of the mission time failure model with the LOOP recovery time model. In essence, removing these events is equivalent to assuming that none of the LOOP cut sets with time-dependent failures occur. This approximates a "perfect" operator that ensures no additional failures occur, after the initial transient, before off-site power is recovered. This is a very conservative treatment because it is obviously beyond the power of the operators to completely reduce the equipment run-time failure probability to zero or recover off-site power instantly.

Instantaneous recovery of on-site equipment during a loss of off-site power event results in a benefit of approximately $34,000. This analysis case was used to model the benefit of SAMA AC/DC-16.

LOSW

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if an additional diversified service water pump was installed, or if the ECCS pump motors were replaced with air cooled motors. Although the proposed SAMAs would not completely eliminate the potential for core damage due to a loss of the service water, a bounding benefit was estimated by removing service water pump train failure events.

Elimination of all core damage due to loss of service water results in a benefit of approximately $202,000. This analysis case was used to model the benefit of SAMAs CW-09 and CW-13.

LOSWHEP

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if procedures following loss of service water were enhanced. Also, since the results of this analysis case were deemed conservatively representative of other plant support systems, it was used to evaluate the change in the plant risk profile that would be achieved if procedures for other plant support systems were enhanced. Although the proposed SAMAs would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing all service water human failure events. Perfectly reliable recovery of service water results in a benefit of approximately $25,000. This analysis case was used to model the benefit of SAMAs CW-06, CW-21, and CW-23.

MAXBENEFIT

This analysis case was used to determine the maximum benefit attainable by removing all severe accident risk associated with the operation of ANO-2 (i.e., eliminating all contributors to core damage). This analysis case was used to evaluate SAMA candidates suggesting installation of new systems or trains, such as an additional HPSI pump with independent diesel or passive secondary side coolers. Elimination of all core damage results in a benefit of approximately $632,000. This analysis case was used to model the benefit of SAMAs CC-01, CC-02, CC-07, CC-14, FW-15, FW-18, OT-02 and OT-06.

OFFSITE

This analysis case was used to assess the total elimination of all off-site release from the plant following an accident resulting in degradation of the reactor core. A number of the SAMAs are associated with reducing the magnitude or consequences of an off-site release. Although the proposed modifications would not be expected to reduce the actual off-site consequences to zero this bounding case estimated the maximum benefit attainable by totally eliminating off-site release. This case is equal to the total off-site benefit of the MAXBENEFIT case. Elimination of all off-site releases results in a benefit of approximately $178,000. This analysis case was used to model the benefit of SAMAs CB-07, EV-02, EV-04, EV-05, EV-07, EV-08, EV-09, EV-10, EV-11, EV-12, EV-19, EV-20, EV-21, EV-22, EV-23, EV-25, EV-26, EV-27, EV-28 and EV-29.

RASLEVEL

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if an additional RAS level transmitter was installed and the logic changed from 2-out-of-4 to 2-out-of-5. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing the RAS level transmitter failure events. Elimination of all core damage due to failure of the recirculation actuation signal level transmitters results in a benefit of approximately $5,000. This analysis case was used to model the benefit of SAMA CC-23.

SEALLOCA

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the reactor coolant pumps automatically tripped on a loss of CCW, if the reactor coolant pump seals were improved, or if an independent reactor coolant pump seal injection system was installed. Although the proposed SAMAs would not completely eliminate the potential for a seal LOCA, a bounding benefit was estimated by removing the reactor coolant pump seal LOCA gate. Elimination of all seal LOCAs results in a benefit of approximately $71,000. This analysis case was used to model the benefit of SAMAs CW-10, CW-11, CW-14, and CW-24.

SGTR

This analysis case was used to evaluate modifications that would reduce the frequency of tube ruptures or would improve the ability to mitigate a SGTR. Although none of the proposed changes would reduce the core damage contribution from SGTRs to zero, a bounding benefit was estimated by removing the SGTR initiating event. Elimination of all steam generator tube ruptures results in a benefit of approximately $25,000. This analysis case was used to model the benefit of SAMAs CB-01, CB-03, CB-04, CB-08, and CB-10.

SIGNAL

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if operator response to inadvertent actuation signals of engineered safety functions was enhanced by additional training. Although the proposed SAMA would not completely eliminate the impact of inadvertent actuation, a bounding benefit was removing all of the gates for spurious actuation of engineered safety functions. Assuming perfect reliability of 120VAC buses results in a benefit of approximately $5,000. This analysis case was used to model the benefit of SAMA AC/DC-06.

SIMOV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if bypass flow paths were provided for all safety injection tank discharge lines. Although the proposed SAMA would not completely eliminate the effects of this potential failure, a bounding benefit was estimated by removing all failures of the safety injection tank discharge MOVs. Elimination of all core damage due to failure of safety injection tank discharge valves results in a benefit of approximately $4,000. This analysis case was used to model the benefit of SAMA CC-24.

SPRAYMOV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the containment spray MOV actuators were diversified. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing the containment spray MOV common cause failure events. Elimination of all core damage due to common cause failure of containment spray valves results in a benefit of approximately $38,000. This analysis case was used to model the benefit of SAMA EV-30.

SUMPMOV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the containment sump motor-operated valves were diversified. Although the proposed SAMA would not completely eliminate the potential failure of containment sump MOVs, a bounding benefit was estimated by removing all containment sump MOV failure events. Elimination of all core damage due to containment sump valve failures results in a benefit of approximately $31,000. This analysis case was used to model the benefit of SAMA CC-20.

SUMPSTRAIN

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if the containment sump strainers were modified to prevent plugging. Although the proposed SAMA would not completely eliminate sump strainer plugging, a bounding benefit was estimated by removing the containment sump strainer failure event. Elimination of sump strainer plugging contribution to core damage results in a benefit of approximately $36,000. This analysis case was used to model the benefit of SAMA CC-18.

SWMOV

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if redundant control valves were placed in series with the service water to CCW isolation valves. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing the service water to CCW isolation valve failure to close event. Elimination of all core damage due to service water to CCW isolation valve failure results in a benefit of approximately $10,000. This analysis case was used to model the benefit of SAMA CW-25.

TDPUMPDC

This analysis case was used to evaluate the change in the plant risk profile that would be achieved if portable generators were used to power the turbine driven emergency feedwater pump controls after station batteries are depleted. Although the proposed SAMA would not completely eliminate the potential for such a failure, a bounding benefit was estimated by removing the DC power gates to the turbine driven emergency feedwater pump logic. Elimination of turbine-driven pump dependence on DC power results in a benefit of approximately $5,000. This analysis case was used to model the benefit of SAMA FW-08.

Values for avoided public and occupational health risk were converted to a monetary equivalent (dollars) via application of the NUREG/BR-0184 (Reference E.2-7) conversion factor of $2,000 per person-rem and discounted to present value. Values for avoided off-site economic costs were also discounted to present value. If the net value of a SAMA was negative, the cost of the enhancement was greater than the benefit and the SAMA was not cost beneficial.

The expected cost of implementation of each SAMA was established from existing estimates of similar modifications combined with engineering judgment. Most of the cost estimates were developed from similar modifications considered in previous performed SAMA and SAMDA analyses. In particular, these cost-estimates were derived from the three major sources including:

Calvert Cliffs SAMA Analysis (Reference E.2-1)

Westinghouse-CE System 80+ SAMDA Analysis (Reference E.2-2)

ANO-1 SAMA Analysis (Reference E.2-3)

The cost estimates did not include the cost of replacement power during extended outages required to implement the modifications, nor did they include contingency costs associated with unforeseen implementation obstacles. Estimates based on modifications that were implemented or estimated in the past were presented in terms of dollar values at the time of implementation (or estimation), and were not adjusted to present-day dollars. In addition, several implementation costs were originally developed for SAMDA analyses (i.e., during the design phase of the plant), and therefore, do not capture the additional costs associated with performing design modifications to existing plants (i.e., reduced efficiency, minimizing dose, disposal of contaminated material, etc.). Therefore, the cost estimates were conservative.

As this analysis focuses on establishing the economic viability of potential plant enhancement when compared to attainable benefit, often detailed cost estimates were not required to make informed decisions regarding the economic viability of a particular modification. Several of the SAMA candidates were clearly in excess of the attainable benefit estimated from a particular analysis case. For less clear cases, engineering judgment was applied to determine if a more detailed cost estimate was necessary to formulate a conclusion regarding the economic viability of a particular SAMA. In most cases, more detailed cost estimates were not required, particularly if the SAMA called for the implementation of a hardware modification. Nonetheless, the cost of all SAMA candidates was conceptually estimated to the point where conclusions regarding the economic viability of the proposed modification could be adequately gauged.

The cost-benefit comparison and disposition of each of the 93 SAMA candidates is presented in Table E.2-1.

E.2.4 <u>Sensitivity Analyses</u>

Several sensitivity analyses were conducted to gauge the impact of assumptions upon the analysis. The benefits estimated for each of these sensitivities are presented in Table E.2-2.

A description of each sensitivity case follows:

<u>Sensitivity Case #1: Repair/Refurbishment</u>

The purpose of this sensitivity case was to investigate the impact of assuming damaged plant equipment is repaired and refurbished following an accident scenario, as opposed to automatically decommissioning the facility following the event. For the purpose of this analysis, the cost of repair and refurbishment over the lifetime of the plant was assumed to be equivalent to 20% of the replacement power cost in accordance with NUREG/BR-0184 (Reference E.2-7). The sensitivity case #1 results for all of the SAMA candidates were lower than the base case results and therefore, lower than the estimated costs.

Sensitivity Case #2: Conservative Discount Rate

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the discount rate. The discount rate of 7.0% used in the base case analyses is conservative relative to corporate practices. Nonetheless, a lower discount rate of 5.0% was assumed in this case. The sensitivity case #2 results for a few of the SAMA candidates were slightly higher than the estimated cost. However, due to conservatism in the benefit estimates and the sensitivity case results, and the fact that most of the costs were estimated only to the point of obtaining reasonable assurance that they were higher than the baseline benefit estimate, these SAMA candidates are still not cost effective for ANO-2.

Sensitivity Case #3: Best-Estimate Discount Rate

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the discount rate. The discount rate of 7.0% used in the base case analyses is considered conservative. This analysis case uses a higher discount rate of 15%, as suggested by Entergy, as a best estimate rate to investigate the impact on each analysis case. The sensitivity case #3 results for all of the SAMA candidates were lower than the base case results and therefore, lower than the estimated costs.

Sensitivity Case #4: High Estimated Dose (On-Site)

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the on-site dose estimates. For the base case analyses, the immediate and long-term on-site dose to plant personnel following a severe accident was assumed to be 3,300 and 20,000 rem respectively. This analysis case assumed high estimated dose values of 14,000 and 30,000 rem for immediate and long-term on-site dose, respectively, as suggested in NUREG/BR-0184 (Reference E.2-7). The sensitivity case #4 results for a few of the SAMA candidates were slightly higher than the estimated cost. However, due to conservatism in the benefit estimates and the sensitivity case results, and the fact that most of the costs were estimated only to the point of obtaining reasonable assurance that they were higher than the base case benefit estimate, these SAMA candidates are still not cost effective for ANO-2.

Sensitivity Case #5: High On-Site Cleanup Cost

The purpose of this sensitivity case was to investigate the sensitivity of each analysis case to the total on-site cleanup cost. For the base case analyses, the total on-site cleanup cost following a severe accident was assumed to be $1,500,000. This analysis case assumed a high estimated on-site cleanup cost of $2,000,000 as suggested in NUREG/BR-0184 (Reference E.2-7). The sensitivity case #5 results for a few of the SAMA candidates were slightly higher than the estimated cost. However, due to conservatism in the benefit estimates and the sensitivity case results, and the fact that most of the costs were estimated only to the point of obtaining reasonable assurance that they were higher than the base case benefit estimate, these SAMA candidates are still not cost effective for ANO-2.

E.2.5 References

E.2-1 Generic Environmental Impact Statement for License Renewal of Nuclear Plants, (regarding Calvert Cliffs Nuclear Power Plant, Units 1 and 2), U.S. Nuclear Regulatory Commission, NUREG-1437, Supplement 1.

E.2-2 Final Safety Evaluation Report Related to the Certification of the System 80+ Design, NUREG 1462, NRC, August 1994.

E.2-3 Arkansas Nuclear One Unit 1 SAMA Analysis, E.A. Krantz, Analysis File Number ANO1 AF-3, Report Number 99-R-1007-01, January 2000.

E.2-4 ANO-2 Probabilistic Risk Assessment (PRA) Individual Plant Examination (IPE) Submittal, Report Number 94-R-2005-01, March 1994.

E.2-5 Individual Plant Examination of External Events/Fires, T.D. Robinson, Report Number 85-E-0053-48, Rev. 2, March 1996

See also:

ANO-2 IPEEE Fire P2 Values, R. Harris, Report Number 95-E-0066-01, Rev. 2, January 1999.

IPEEE High Confidence of Low Probability of Failure (HCLPF) Calculations for ANO-2 Mechanical and Electrical Equipment and Block Walls, Report Number 96-SQ-2001-01, Rev. 1, May 1996.

IPEEE Other Events, Report Number 94-R-0016-01, Rev.1, December 1994.

IPEEE Seismic Margins Assessment (SMA) of Arkansas Nuclear One, Unit 2, Report Number 96-R-2016-02, Rev. 0, May 1996.

USI A-46/IPEEE Horizontal Tank and Heat Exchanger Report and Review, Report Number 95-SQ-2021-02, Rev. 0, September 1996

E.2-6 *SW Pump Strainer Backwash Device*, ER010551R201 Rev. 0, November, 2001.

E.2-7 *Regulatory Analysis Technical Evaluation Handbook*, NUREG/BR-0184, January 1997.

E.2-8 *ANO-2 ATWS Scoping Report*, 89-E-0048-26, Rev 2, December 1997.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO AC/DC POWER RELIABILITY OR AVAILIABILITY								
AC/DC-02	Install a combustion turbine generator	Improve on-site AC power reliability (i.e., decrease the frequency of a station blackout).	6.08%	5.92%	$39,000	$3,350,000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $3,350,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-04	Use fuel cells in lieu of conventional lead-acid batteries	Extend DC power availability during a station blackout event by replacing station batteries with fuel cells that would extend DC power availability to 24 hours.	5.70%	4.25%	$34,000	$2,000,000	Not Cost Effective	Station battery capacity of 24 hours results in a benefit of $34,000 (analysis case DCPWR). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $2,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-05	Provide additional DC battery capability	Ensure longer battery life during a station blackout and consequently reduce exposure to long term station blackout sequences.	5.70%	4.25%	$34,000	>$150,000	Not Cost Effective	Station battery capacity of 24 hours results in a benefit of $34,000 (analysis case DCPWR). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $150,000 per battery bank. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-06	Train operations crew for response to inadvertent actuation signals	Improve the chance of successful response to loss of two 120VAC buses.	0.90%	0.43%	$5,000	$35,000	Not Cost Effective	Assuming perfect reliability of 120VAC buses results in a benefit of $5,000 (analysis case SIGNAL). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO AC/DC POWER RELIABILITY OR AVAILIABILITY								
AC/DC-09	Improve bus cross-tie capability	Improve AC power reliability by installing automatic bus cross-tie capabilities.	6.08%	5.92%	$39,000	$1,119,000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $1,119,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-10	Incorporate alternate battery charging capabilities	Improve DC power reliability by either cross-tying the AC buses, or installing a portable diesel-driven battery charger.	5.70%	4.25%	$34,000	$134,000	Not Cost Effective	Station battery capacity of 24 hours results in a benefit of $34,000 (analysis case DCPWR). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $134,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-12	Replace current station batteries with a more reliable model	Improve DC power reliability by installing more reliable station batteries.	5.70%	4.25%	$34,000	>$150,000	Not Cost Effective	Station battery capacity of 24 hours results in a benefit of $34,000 (analysis case DCPWR). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $150,000 per battery bank. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-13	Create AC power cross tie capability across units at a multi-unit site	Improve AC power reliability by installing AC power cross-tie capabilities between ANO-1 and ANO-2.	6.08%	5.92%	$39,000	>>$39,000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO AC/DC POWER RELIABILITY OR AVAILIABILITY								
AC/DC-15	Develop enhanced procedures to repair or change out failed 4KV breakers	Increase probability of recovery from a failure of breakers that transfer 4.16 kV non-emergency buses from unit station service transformers to system station service transformers. These failures, in conjunction with failure of the diesel generators, lead to loss of emergency AC power.	1.11%	0.59%	$6,000	$35,000	Not Cost Effective	Elimination of all 4160V breaker failures results in a benefit of $6,000 (analysis case BRKR). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-16	Emphasize steps in plant recovery following a station blackout event	Reduce human error associated with recovery of station blackout events through enhanced training and procedural guidance.	5.30%	5.32%	$34,000	$35,000	Not Cost Effective	Instantaneous recovery of on-site equipment during a loss of off-site power event results in a benefit of $34,000 (analysis case LOOPREC). As discussed in Section E.2, the LOOPREC benefit estimate is very conservative. Also, emphasizing recovery of off-site power in operator training may be detrimental to other necessary recovery actions, negating some of the benefit. Thus, the attainable benefit for this SAMA is much less than $34,000. At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO AC/DC POWER RELIABILITY OR AVAILIABILITY								
AC/DC-19	Create a back-up source for diesel cooling	Provide a redundant source of diesel cooling by making the emergency diesel generators air-cooled.	3.15%	3.14%	$20,000	$1,700,000	Not Cost Effective	Perfectly reliable EDG cooling results in a benefit of $20,000 (analysis case EDGCOOL). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $1,700,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-20	Use fire protection systems as a backup for diesel cooling	Provide redundancy for the diesel cooling support systems.	6.08%	5.92%	$39,000	>$497, 000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $497,000 per diesel generator. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-21	Provide a connection to an alternate off-site power source	Increase off-site power redundancy.	6.08%	5.92%	$39,000	>$25,000,000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $25,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AC/DC-22	Implement underground off-site power lines	Improve off-site power reliability, particularly during severe weather.	6.08%	5.92%	$39,000	>$25,000,000	Not Cost Effective	Elimination of all loss of off-site power initiators results in a benefit of $39,000 (analysis case LOOP). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $25,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO AC/DC POWER RELIABILITY OR AVAILIABILITY								
AC/DC-24	Create the ability to automatically transfer battery charger/eliminator 2D31B to an alternate power source upon demand	Reduce the potential for human error in transferring battery charger 2D31B to an alternate power source.	5.70%	4.25%	$34,000	>>$34,000	Not Cost Effective	Station battery capacity of 24 hours results in a benefit of $34,000 (analysis case DCPWR). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO ATWS COPING								
AT-01	Provide alternative ATWS pressure relief valves	Install a system of relief valves to prevent equipment damage from a primary coolant pressure spike during an ATWS sequence. This enhancement would improve equipment availability following an ATWS.	22.2%	Not Estimated	$140,000	$1,000,000	Not Cost Effective	Elimination of core damage due to an ATWS results in a benefit of $140,000 (analysis case ATWS1). The proposed modification would result in only a fraction of this benefit. In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
AT-02	Create a boron injection/shutdown system to backup the mechanical control rods	Create a boron injection system by modifying the reactor coolant pump seal cooling system to inject boron using existing sources of boron and existing piping and valves. This enhancement would provide a redundant means to shut down the reactor.	22.2%	Not Estimated	$140,000	$300,000	Not Cost Effective	Elimination of core damage due to an ATWS results in a benefit of $140,000 (analysis case ATWS1). The proposed modification would result in only a fraction of this benefit. In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $300,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO ATWS COPING								
AT-03	Provide a diverse plant protection system	Provide an additional diversified plant protection system to reduce the frequency of ATWS events (e.g., ATWS mitigation scram actuation circuitry).	22.2%	Not Estimated	$140,000	$3,000,000	Not Cost Effective	Elimination of core damage due to an ATWS results in a benefit of $140,000 (analysis case ATWS1). The proposed modification would result in only a fraction of this benefit. In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $3,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO IDENTIFYING OR COPING WITH CONTAINMENT BYPASS								
CB-01	Institute a maintenance practice to perform a 100% inspection of steam generator tubes during each refueling outage	Perform eddy-current testing on 100% of the steam generator tubes during each refueling outage to reduce the frequency of steam generator tube rupture events.	2.02%	7.52%	$25,000	$1,500,000	Not Cost Effective	Elimination of all steam generator tube ruptures results in a benefit of $25,000 (analysis case SGTR). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CB-03	Increase the pressure capacity of the secondary side	Increase the secondary side pressure capacity enough that a steam generator tube rupture would not cause the relief valves to lift. This would prevent a direct release pathway to the environment following a steam generator tube rupture.	2.02%	7.52%	$25,000	>>$25,000	Not Cost Effective	Elimination of all steam generator tube ruptures results in a benefit of $25,000 (analysis case SGTR). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO IDENTIFYING OR COPING WITH CONTAINMENT BYPASS								
CB-04	Install a redundant spray system to depressurize the primary system during a steam generator tube rupture	Enhance depressurization capabilities during steam generator tube rupture.	2.02%	7.52%	$25,000	$5,000,000	Not Cost Effective	Elimination of all steam generator tube ruptures results in a benefit of $25,000 (analysis case SGTR). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $5,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CB-07	Provide main steam safety valve and automatic depressurization valve scrubbing	Route the discharge from the main steam safety valves and automatic depressurization valves through a structure in which a water spray condenses the steam and removes most of the fission products. This enhancement would reduce the consequences of a steam generator tube rupture.	0%	100%	$178,000	$9,500,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $9,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CB-10	Direct steam generator flooding after a steam generator tube rupture, prior to core damage	Improve scrubbing of steam generator tube rupture releases by maintaining adequate water coverage of a ruptured steam generator tube.	2.02%	7.52%	$25,000	$35,000	Not Cost Effective	Elimination of all steam generator tube ruptures results in a benefit of $25,000 (analysis case SGTR). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO IDENTIFYING OR COPING WITH CONTAINMENT BYPASS								
CB-13	Install additional instrumentation for interfacing system LOCA sequences	Install pressure or leak monitoring instruments between the first two pressure isolation valves on low-pressure injection lines, residual heat removal suction lines, and high pressure injection lines to increase the ability to detect an interfacing system LOCA.	4.56%	35.87%	$86,000	$2,300,000	Not Cost Effective	Elimination of all core damage from ISLOCA results in a benefit of $86,000 (analysis case ISLOCA). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $2,300,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CB-14	Increase frequency of valve leak testing	Reduce the frequency of an interfacing system LOCA.	4.56%	35.87%	$86,000	>$86,000	Not Cost Effective	Elimination of all core damage from ISLOCA results in a benefit of $86,000 (analysis case ISLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CB-19	Ensure all interfacing system LOCA releases are scrubbed	Scrub interfacing system LOCA releases. One method would be to plug drains in the break area so the break point would be covered with water.	4.56%	35.87%	$86,000	>>$86,000	Not Cost Effective	Elimination of all core damage from ISLOCA results in a benefit of $86,000 (analysis case ISLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO IDENTIFYING OR COPING WITH CONTAINMENT BYPASS								
CB-20	Add redundant and diverse limit switch to each containment isolation valve	Enhance isolation valve position indication, reducing the frequency of containment isolation failure and interfacing system LOCAs.	4.56%	35.87%	$86,000	$1,000,000	Not Cost Effective	Elimination of all core damage from ISLOCA results in a benefit of $86,000 (analysis case ISLOCA). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CB-23	Develop enhanced procedures for station blackout to prevent containment bypass	Add a procedural requirement to close manual valve 2HPA-2 to ensure that failure of 2SV-8231-2 will not introduce a small containment leak path.	0.02%	0.04%	$200	$35,000	Not Cost Effective	Elimination of all core damage attributable to plant damage state SBOu results in a benefit of $200 (analysis case CBPEN). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CB-26	Enhance plant procedures to improve credit for human action to prevent and cope with an interfacing system LOCA	Change plant operating procedures to isolate the low pressure safety injection line following the failure of series system check valves. Also, enhance operator training on coping with interfacing system LOCAs resulting from reactor coolant pump seal cooler tube ruptures.	3.36%	26.40%	$64,000	>$70,000	Not Cost Effective	Elimination of all human error associated with an interfacing system LOCA results in a benefit of $64,000 (analysis case ISLOCAHEP). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since several systems are impacted, this modification requires multiple procedure revisions. Implementation would also require increasing the inspection frequency for shutdown cooling suction line MOVs. As this SAMA requires multiple procedure modifications and in-service inspection costs, the cost of implementing this SAMA is >$70,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO CORE COOLING SYSTEMS								
CC-01	Provide capability for diesel-driven, low pressure vessel makeup	Provide an extra water source during sequences in which the reactor is depressurized and all other injection is unavailable (e.g., fire protection system).	100%	100%	$632,000	>$632,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CC-02	Provide an additional high pressure injection pump with independent diesel	Reduce frequency of core melt from small LOCA sequences during station blackout events.	100%	100%	$632,000	$5,000,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $5,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO CORE COOLING SYSTEMS								
CC-07	Extend the reactor water storage tank source	Extend the reactor water storage tank capacity in the event of steam generator tube ruptures. Since the time available for recovery depends mostly on the refueling water storage tank inventory, the ability to refill the tank once it reaches a specified low level could prolong the cooling of the core for an indefinite period. Steam generator tube leak rate would need to be decreased (i.e., through primary system depressurization) to less than the available refueling water storage tank makeup capacity.	100%	100%	$632,000	$1,000,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CC-14	Replace two of the four electric safety injection pumps with diesel-powered pumps	Reduce the probability of common cause failure of the safety injection system. This SAMA was originally intended for the Westinghouse-CE System 80+, which has four trains of safety injection. However, the intent of this SAMA is to provide diversity within the high- and low-pressure safety injection systems.	100%	100%	$632,000	$2,000,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $2,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO CORE COOLING SYSTEMS								
CC-18	Modify the containment sump strainers to prevent plugging	Prevent plugging of the containment sump strainers by modifying the existing strainers and adding additional strainer area.	7.54%	0.88%	$36,000	>>$36,000	Not Cost Effective	Elimination of sump strainer plugging contribution to core damage results in a benefit of $36,000 (analysis case SUMPSTRAIN). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CC-19	Provide an additional flow path from the refueling water tank to the high-pressure safety injection system through a diversified suction flow path check valve	Reduce the potential for common cause failure of the refueling water tank flow path check valves.	5.45%	2.61%	$29,000	>>$29,000	Not Cost Effective	Elimination of all core damage due to failure of the high-pressure safety injection flow path check valves results in a benefit of $27,000 (analysis case HPSICV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CC-20	Make containment sump recirculation outlet valve motor-operated valves 2CV-5649-1 and 2CV-5650-2 diverse from one another	Replace either containment sump valve 2CV-5649-1 or 2CV-5650-2 with an air-operated valve. This would reduce the potential for common cause failure of these valves.	5.75%	2.75%	$31,000	>$31,000	Not Cost Effective	Elimination of all core damage due to containment sump valve failures results in a benefit of $31,000 (analysis case SUMPMOV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO CORE COOLING SYSTEMS								
CC-21	Provide actuator diversity for the motor-operated valves in the high-pressure safety injection system	Reduce the potential for common cause failure of high-pressure safety injection motor-operated valves by replacing redundant train valve actuators with diversified valve actuators.	4.06%	1.99%	$22,000	>$22,000	Not Cost Effective	Elimination of all core damage due to common cause failure of the high-pressure safety injection valves results in a benefit of $21,000 (analysis case HPSIMOV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CC-22	Incorporate diversity among recirculation actuation signal and engineered safety features actuation signal actuation relays	Reduce the potential for common cause failure of two or more recirculation actuation signal and engineered safety features actuation signal actuation relays (e.g., K104A/B, SSR-1/3A, etc.) This modification would replace existing relays with relays of diverse design.	2.44%	2.01%	$15,000	>$15,000	Not Cost Effective	Elimination of all core damage due to common cause failure of engineered safety features actuation and solid state relays results in a benefit of $15,000 (analysis case ESFASRELAY). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CC-23	Provide an additional recirculation actuation signal level transmitter (2LT-5636-5) and change recirculation actuation logic from 2-out-of-4 to 2-out-of-5	Increase the reliability of automatic recirculation swap-over. This modification would install an additional level transmitter and change the recirculation actuation logic from 2-out-of-4 to 2-out-of-5.	0.97%	0.09%	$5,000	>$5,000	Not Cost Effective	Elimination of all core damage due to failure of the recirculation actuation signal level transmitters results in a benefit of $5,000 (analysis case RASLEVEL). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO CORE COOLING SYSTEMS								
CC-24	Provide bypass flow paths for all safety injection tanks	Provide a bypass flow path with a normally open motor-operated control valve around the safety injection tank discharge control valves. This modification would increase the probability of injection if the motor-operated control valves fail closed.	0.91%	0.15%	$4,000	>>$4,000	Not Cost Effective	Elimination of all core damage due to failure of safety injection tank discharge valves results in a benefit of $4,000 (analysis case SIMOV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-01	Cap downstream piping of normally closed component cooling water drain and vent valves	Reduce the frequency of loss of component cooling water initiating events, some of which are attributable to catastrophic failure of one of the m single isolation valves.	19.99%	11.94%	$112,000	>$112,000	Not Cost Effective	Elimination of all core damage due to loss of feedwater results in a benefit of $112,000 (analysis case FDW). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
CW-06	On loss of essential raw cooling water, proceduralize shedding component cooling water loads to extend the component cooling water heatup time	Increase time before reactor coolant pump seal failure during loss of service water sequences.	4.55%	2.74%	$25,000	$35,000	Not Cost Effective	Perfectly reliable recovery of service water results in a benefit of $25,000 (analysis case LOSWHEP). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-07	Increase charging pump lube oil capacity	This SAMA was intended to improve the reliability of seal cooling during normal operation via seal injection. Although ANO-2 does not use seal injection for seal cooling during normal operation, the charging pumps have a risk significant function to add boron to the RCS in the event of an ATWS.	1.95%	Not Estimated	$12,000	>>$12,000	Not Cost Effective	Making the charging pumps perfectly reliable results in a benefit of $12,000 (analysis case ATWS2). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CW-09	Provide an additional diversified service water pump	Decrease the frequency of core damage due to a loss of service water by installing an additional service water pump with an independent diesel generator. This modification also requires that one of the remaining service water pumps be supplied with an independent diesel to reduce the potential for common cause failure of all of the service water pumps.	32.16%	33.45%	$202,000	>$202,000	Not Cost Effective	Elimination of all core damage due to loss of service water results in a benefit of $202,000 (analysis case LOSW). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-10	Create an independent reactor coolant pump seal injection system, with dedicated diesel	Add redundant reactor coolant pump seal cooling, reducing the frequency of core damage from loss of component cooling water, service water, or station blackout. (Note: the Westinghouse-CE System 80+ includes a dedicated, positive displacement seal injection pump (air-cooled) independent of component cooling water.)	11.82%	10.71%	$71,000	>>$71,000	Not Cost Effective	Elimination of all seal LOCAs results in a benefit of $71,000 (analysis case SEALLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CW-11	Create an independent reactor coolant pump seal injection system, without dedicated diesel	Add redundant reactor coolant pump seal cooling, reducing the frequency of core damage from loss of component cooling water or service water, but not from a station blackout.	11.82%	10.71%	$71,000	>>$71,000	Not Cost Effective	Elimination of all seal LOCAs results in a benefit of $71,000 (analysis case SEALLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CW-13	Replace emergency core cooling system pump motors with air cooled motors	Eliminate emergency core cooling system dependence on service water.	32.16%	33.45%	$202,000	>$202,000	Not Cost Effective	Elimination of all core damage due to loss of service water results in a benefit of $202,000 (analysis case LOSW). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-14	Install improved reactor coolant pump seals	Reactor coolant pump seal O-rings constructed of improved materials would reduce the likelihood of reactor coolant pump seal LOCA.	11.82%	10.71%	$71,000	$2,500,000	Not Cost Effective	Elimination of all seal LOCAs results in a benefit of $71,000 (analysis case SEALLOCA). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $2,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CW-15	Install an additional component cooling water pump	Reduce the likelihood of loss of component cooling water leading to a reactor coolant pump seal LOCA.	12.71%	11.47%	$76,000	>>$76,000	Not Cost Effective	Elimination of all core damage due to loss of the component cooling water system results in a benefit of $76,000 (analysis case LOCCW). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CW-21	Implement procedure and operator training enhancements for support system failure sequences, with an emphasis on anticipating problems and coping	Improve the success rate of operator actions after support system failures.	4.55%	2.74%	$25,000	$35,000	Not Cost Effective	Perfectly reliable recovery of service water results in a benefit of $25,000 (analysis case LOSWHEP). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-22	Improve ability to cool residual heat removal heat exchangers	Reduce the chance of loss of decay heat removal by: (1) modifying procedures and hardware to allow manual alignment of the fire protection system to the component cooling water system; or (2) installing a component cooling water header cross-tie.	12.71%	11.47%	$76,000	$565,000	Not Cost Effective	Elimination of all core damage due to loss of the component cooling water system results in a benefit of $76,000 (analysis case LOCCW). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $565,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CW-23	Develop enhanced procedures for loss of service water	Enhance loss of service water procedures to improve the ability to avoid unnecessary low pressure safety injection and containment spray pump overheating failures that can minimize the benefit of restoring service water.	4.55%	2.74%	$25,000	$35,000	Not Cost Effective	Perfectly reliable recovery of service water results in a benefit of $25,000 (analysis case LOSWHEP). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
CW-24	Provide the ability to automatically trip the reactor coolant pumps on a loss of component cooling water	Reduce the potential for a seal LOCA following loss of component cooling water by reducing reliance on operator action to trip the reactor coolant pumps.	11.82%	10.71%	$71,000	>$71,000	Not Cost Effective	Elimination of all seal LOCAs results in a benefit of $71,000 (analysis case SEALLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-25	Add redundant control valve in series with 2CV-1530-1	Add a redundant valve in series with 2CV-1530-1 on service water header 1 (and 2CV-1531-2 on service water header 2). This SAMA would increase the reliability of isolation if the isolation valves supplying the component cooling water heat exchangers and main chillers fail to close upon demand.	1.62%	1.64%	$10,000	>$10,000	Not Cost Effective	Elimination of all core damage due to service water to CCW isolation valve failure results in a benefit of $10,000 (analysis case SWMOV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
CW-26	Increase inspections of service water pump discharge filters	Reduce the failure frequency of the service water system. This SAMA would increase the inspection and cleaning frequency of the service water pump discharge filters, reducing the probability of a common cause failure.	16.17%	16.36%	$100,000	>$100,000	Not Cost Effective	Elimination of all common cause failures of service water pump discharge filters results in a benefit of $100,000 (analysis case FILTER). Currently, weekly cleaning of the service water strainer for one pump requires about six hours. Assuming $20/hour and bi-weekly cleaning for each strainer, the cost would be >$100,000 well before the end of the license renewal period. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO LOSS OF COOLING WATER								
CW-27	Replace current service water pump discharge strainers with backwash filters	Reduce the failure frequency of the service water system. This SAMA would install backwash filters in place of the existing strainers, reducing the probability of a common cause failure.	16.17%	16.36%	$100,000	>$200,000	Not Cost Effective	Elimination of all common cause failures of service water pump discharge filters results in a benefit of $100,000 (analysis case FILTER). It was estimated that the material and installation of backwash filters for all three SW pumps would cost more than $79,000 (Reference E.2-6). With engineering, documentation and training, the total cost would be more than $200,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE								
EV-02	Install automatic containment spray pump header throttle valves	Extend the time during which water remains in the reactor water storage tank, when full containment spray flow is not needed.	0%	100%	$178,000	$375,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $375,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-04	Develop an enhanced drywell spray system	Provide a redundant source of water to the containment to control containment pressure. For a PWR, install a redundant containment spray system.	0%	100%	$178,000	$1,500,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE								
EV-05	Provide a dedicated drywell spray system	Similar to EV-04, except one of the existing spray loops would be used instead of developing a new spray system (i.e., new hardware, existing piping). In a PWR, develop a dedicated containment spray system.	0%	100%	$178,000	>>$178,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
EV-07	Install a filtered containment vent	Assuming injection is available (non-ATWS sequences), provide alternate decay heat removal and fission products scrubbing.	0%	100%	$178,000	$5,700,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $5,700,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
EV-08	Install an unfiltered containment vent	Provide an alternate decay heat removal method (non-ATWS) without fission product scrubbing.	0%	100%	$178,000	$3,100,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $3,100,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-09	Create/enhance hydrogen control system with independent power supply	Reduce hydrogen detonation using either a new, independent power supply; a non-safety grade portable generator; existing station batteries; or existing AC/DC independent power supplies, such as the security system diesel.	0%	100%	$178,000	$1,000,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
<u>ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE</u>								
EV-10	Create a passive hydrogen control system	Reduce hydrogen detonation potential without requiring electric power.	0%	100%	$178,000	$800,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $800,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-11	Create a refractory-lined crucible with heat removal potential under the basemat to contain molten debris	Provide a ceramic-lined concrete crucible and cooling system in the reactor cavity. A molten core escaping from the vessel would be contained within the crucible. Water cooling of the cruc ble would cool the molten core, preventing melt-through.	0%	100%	$178,000	$108,000,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $108,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
EV-12	Create a water cooled rubble bed on the pedestal	Provide a bed of refractory pebbles to impede the flow of molten corium to the concrete drywell structures and increase the available heat transfer area.	0%	100%	$178,000	$19,000,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $19,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE								
EV-15	Create a reactor cavity flooding system	Enhance the ability to cool debris, reduce core-concrete interaction, and provide fission product scrubbing.	1.48%	5.36%	$17,000	$8,750,000	Not Cost Effective	Elimination of core damage attributable to plant damage state IVKi results in a benefit of $17,000 (analysis case CAVITY). In 1999, the cost of implementing a similar SAMA at ANO-1 was estimated to be $8,750,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-16	Creating other options for reactor cavity flooding (Option 1)	Drill pathways in the reactor vessel support structure to allow drainage from the steam generator compartments, refueling canal, sumps, etc., to flood the reactor cavity. Also (for ice condensers), allow drainage of water from melted ice into the reactor cavity. This SAMA would enhance the ability to cool debris, reduce core-concrete interaction, and provide fission product scrubbing.	1.48%	5.36%	$17,000	>>$17,000	Not Cost Effective	Elimination of core damage attributable to plant damage state IVKi results in a benefit of $17,000 (analysis case CAVITY). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
EV-17	Creating other options for reactor cavity flooding (Option 2)	Flood the reactor cavity via systems l ke the diesel-driven fire pumps to enhance the ability to cool debris, reduce core concrete interaction, and provide fission product scrubbing.	1.48%	5.36%	$17,000	>>$17,000	Not Cost Effective	Elimination of core damage attributable to plant damage state IVKi results in a benefit of $17,000 (analysis case CAVITY). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
<u>ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE</u>								
EV-19	Provide a core debris control system	Prevent direct core debris attack of the primary containment steel shell by erecting a barrier to protect the containment walls from ejected core debris following a core melt scenario at high pressure.	0%	100%	$178,000	$45,000,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $45,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-21	Provide containment inerting capability	Prevent combustion of hydrogen and carbon monoxide gases.	0%	100%	$178,000	$10,900,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1999, the cost of implementing a similar SAMA at ANO-1 was estimated to be $10,900,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-22	Use fire water spray pump for containment spray	Provide a redundant containment spray method.	0%	100%	$178,000	$565,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $565,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
EV-23	Install a passive containment spray system	Provide containment spray with very high reliability and without support systems.	0%	100%	$178,000	>>$178,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE								
EV-25	Increase containment design pressure	Reduce the chance of containment overpressure.	0%	100%	$178,000	>>$178,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
EV-26	Provide an alternative concrete composition in the reactor cavity	Use an advanced concrete composition in the reactor cavity or increase the thickness of the concrete basemat to prevent basemat melt-through.	0%	100%	$178,000	$5,000,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $5,000,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
EV-27	Provide a reactor vessel exterior cooling system	Modify the reactor cavity configuration to externally cool the lower head of the reactor vessel following a core melt accident. This SAMA has the potential to cool a molten core before it causes vessel failure.	0%	100%	$178,000	$2,500,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $2,500,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
EV-28	Create a vacuum building	Provide a separate building maintained at vacuum to connect to the primary containment following an accident, thereby depressurizing the primary containment and further reducing emissions from severe accidents.	0%	100%	$178,000	>>$178,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO EX-VESSEL ACCIDENT MITIGATION OR CONTAINMENT PERFORMANCE								
EV-29	Add ribbing to the containment shell	Reduce the potential for buckling of the containment shell due to vacuum conditions (i.e., reverse pressure loadings).	0%	100%	$178,000	>>$178,000	Not Cost Effective	Elimination of all off-site releases results in a benefit of $178,000 (analysis case OFFSITE). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
EV-30	Provide actuator diversity for motor-operated valves in the containment spray system	Reduce the potential for common cause failure of containment spray system motor-operated valves by replacing redundant train motor-operated valve actuators with diverse valve actuators.	6.97%	3.81%	$38,000	>$38,000	Not Cost Effective	Elimination of all core damage due to common cause failure of containment spray valves results in a benefit of $38,000 (analysis case SPRAYMOV). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
EV-31	Remove reactor vessel cavity check valve 2BS-46 internals	Remove check valve internals to improve the potential for cooling communication between molten core debris in the bottom of the cavity and water on the containment floor. Improved cooling of a failed core would decrease the potential for a post severe accident off-site release.	1.48%	5.36%	$17,000	>$17,000	Not Cost Effective	Elimination of core damage attributable to plant damage state IVKi results in a benefit of $17,000 (analysis case CAVITY). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO FEEDWATER OR FEED AND BLEED RELIABILITY OR AVAILIABILITY								
FW-01	Install a digital feedwater upgrade	Reduce the likelihood of loss of main feedwater following a plant trip.	19.99%	11.94%	$112,000	>$112,000	Not Cost Effective	Elimination of all core damage due to loss of feedwater results in a benefit of $112,000 (analysis case FDW). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
FW-08	Provide hookup for portable generators	Temporary connections could allow portable generators to power the turbine-driven auxiliary feedwater pump controls after station batteries are depleted.	0.91%	0.29%	$5,000	>>$5,000	Not Cost Effective	Elimination of turbine-driven pump dependence on DC power results in a benefit of $5,000 (analysis case TDPUMPDC). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
FW-13	Install an independent diesel for the condensate storage tank makeup pumps	Allow continuous makeup to the condensate storage tank during a station blackout event.	17.79%	12.51%	$104,000	$271,000	Not Cost Effective	A perfectly reliable EFW system results in a benefit of $104,000 (analysis case EFW). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $271,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
FW-15	Create passive secondary side coolers	Provide a passive, secondary-side heat-rejection loop consisting of a condenser and heat sink to reduce the potential for core damage due to loss-of-feedwater events.	100%	100%	$632,000	>$632,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO FEEDWATER OR FEED AND BLEED RELIABILITY OR AVAILIABILITY								
FW-17	Enhance emergency feedwater flow control in the emergency operating procedures	Enhance emergency operating procedures to place emergency feedwater flow control valves in an open position once it has been determined that main steam isolation signal conditions do not exist. If the outboard flow control valves from both the motor-driven and turbine-driven were in a full open position upon loss of power supply, the potential for loss of flow to both steam generators would be minimized.	3.42%	0.75%	$17,000	$35,000	Not Cost Effective	Elimination of operator failure to open the emergency feedwater flow control valves results in a benefit of $17,000 (analysis case EFWCV). At ANO-2, the cost of modifying a plant procedure and the associated training is $35,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
FW-18	Replace current pilot operated relief valves with larger ones such that only one is required for successful feed and bleed	Remove potential for common cause failure of the pilot operated relief valves by replacing them with larger ones, such that only one is required.	100%	100%	$632,000	$2,700,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $2,700,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO FEEDWATER OR FEED AND BLEED RELIABILITY OR AVAILIABILITY								
FW-19	Create ability to automatically align emergency feedwater/auxiliary feedwater suction to the other condensate storage tank on low-low level of 2T-41A or 2T-41B	Create the ability to automatically align emergency feedwater/auxiliary feedwater suction to the other condensate storage tank on low-low level of 2T-41A or 2T-41B. This modification would reduce the potential for a loss of feedwater.	1.79%	1.29%	$10,000	>>$10,000	Not Cost Effective	Perfectly reliable re-alignment of EFW/AFW suction to the alternate condensate storage tank results in a benefit of $10,000 (analysis case CST). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO HEATING, VENTILATION AND AIR CONDITIONING								
HV-03	Develop enhanced procedures for temporary HVAC	Reduce probability of failure of HVAC recovery actions through the use of temporary equipment to cool both shutdown heat-exchanger rooms following a loss of two out of three room unit coolers in each room.	27.48%	29.73%	$174,000	>$300,000	Not Cost Beneficial	Perfectly reliable shutdown heat exchanger room cooling results in a benefit of $174,000 (analysis case HVAC). This SAMA requires a 60-ton, temporary industrial coolers for each of the shutdown heat exchanger rooms. The cooler should include a control system, an independent power source and a heat sink other than service water. The equipment must be maintained on-site and inspected/tested regularly for the duration of plant life. Operator training to stage the temporary coolers for appropriate use would also be required. One temporary cooling unit, diesel generator, control system and cooling water interface would cost over $150,000. As this SAMA requires two units, the minimum cost associated with implementation of this SAMA is >$300K. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduction	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
ENHANCEMENTS RELATED TO HEATING, VENTILATION AND AIR CONDITIONING								
HV-05	Create ability to switch fan power supply to station batteries in a station blackout	Allow continued fan operation in a station blackout. (This SAMA was created for a BWR reactor core isolation cooling room at the James A. Fitzpatrick Nuclear Power Plant. However, a similar SAMA may be applied to ANO-2's emergency feedwater room.)	17.79%	12.51%	$104,00	$226,000	Not Cost Effective	A perfectly reliable EFW system results in a benefit of $104,000 (analysis case EFW). In 1998, BG&E estimated the cost of implementing a similar SAMA at Calvert Cliffs to be $226,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
ENHANCEMENTS RELATED TO INSTRUMENT AIR								
IA-02	Replace current air compressors with more reliable models	Improve reliability and increase availability of instrument air compressors.	~0%	~0%	"minimal"	>>"minimal"	Not Cost Effective	Perfectly reliable air compressors result in minimal benefit (analysis case AIR). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.
OTHER ENHANCEMENTS								
OT-02	Create a reactor coolant depressurization system	Primary system depressurization would allow low pressure emergency core cooling system injection in the event of small LOCA and high-pressure safety injection failure. Even if core damage is not prevented, low primary system pressure alleviates some concerns about high pressure melt ejection. Modification could install a new depressurization system or utilize existing pilot-operated relief valves, head vents and secondary side valves.	100%	100%	$632,000	$4,600,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1999, the cost of implementing a similar SAMA at ANO-1 was estimated to be $4,600,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.

Table E.2-1, Summary of SAMA Candidates Considered in Cost-Benefit Evaluation (continued)

SAMA ID	Potential Enhancement	Discussion	CDF Reduc-tion	Off-site Dose Reduction	Estimated Benefit	Estimated Cost	Conclusion	Basis for Conclusion
OT-06	Install secondary side guard pipes up to the main steam isolation valves	Prevent secondary side depressurization if a steam line break occurs upstream of the main steam isolation valves. This SAMA also prevents consequential multiple steam generator tube ruptures following a main steam line break event.	100%	100%	$632,000	$1,100,000	Not Cost Effective	Elimination of all core damage results in a benefit of $632,000 (analysis case MAXBENEFIT). In 1993, the cost of implementing a similar SAMA in the Westinghouse-CE System 80+ was estimated to be $1,100,000. Since the cost of implementing this SAMA exceeds the attainable benefit, this SAMA is not cost effective for ANO-2.
OT-07	Provide digital large break LOCA protection	Installation digital large break LOCA early detection instrumentation to improve the ability to identify precursors of a large break LOCA (i.e., a leak before break).	4.03%	3.49%	$24,000	>>$24,000	Not Cost Effective	Elimination of all core damage due to large LOCAs results in a benefit of $24,000 (analysis case LBLOCA). The cost of implementing this SAMA is judged to exceed the attainable benefit, even without a detailed cost estimate. Therefore, this SAMA is not cost effective for ANO-2.

Table E.2-2, Sensitivity Analysis Results

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
AC/DC -02	Install a combustion turbine generator	$39,000	$3,350,000	$27,000	$42,000	$17,000	$39,000	$43,000
AC/DC -04	Use fuel cells in lieu of conventional lead-acid batteries	$34,000	$2,000,000	$23,000	$37,000	$15,000	$35,000	$38,000
AC/DC -05	Provide additional DC battery capability	$34,000	>$150,000	$23,000	$37,000	$15,000	$35,000	$38,000
AC/DC -06	Train operations crew for response to inadvertent actuation signals	$5,000	$35,000	$3,000	$5,000	$2,000	$5,000	$5,000
AC/DC -09	Improve bus cross-tie capability	$39,000	$1,119,000	$27,000	$42,000	$17,000	$39,000	$43,000
AC/DC -10	Incorporate alternate battery charging capabilities	$34,000	$134,000	$23,000	$37,000	$15,000	$35,000	$38,000
AC/DC -12	Replace current station batteries with a more reliable model	$34,000	>$150,000	$23,000	$37,000	$15,000	$35,000	$38,000
AC/DC -13	Create AC power cross tie capability across units at a multi-unit site	$39,000	>>$39,000	$27,000	$42,000	$17,000	$39,000	$43,000
AC/DC -15	Develop enhanced procedures to repair or change out failed 4KV breakers	$6,000	$35,000	$4,000	$6,000	$3,000	$6,000	$7,000
AC/DC -16	Emphasize steps in plant recovery following a station blackout event	$34,000	$35,000	$24,000	$37,000	$15,000	$34,000	$38,000
AC/DC -19	Create a back-up source for diesel cooling	$20,000	$1,700,000	$14,000	$22,000	$9,000	$20,000	$22,000
AC/DC -20	Use fire protection systems as a backup for diesel cooling	$39,000	>$497, 000	$27,000	$42,000	$17,000	$39,000	$43,000
AC/DC -21	Provide a connection to an alternate off-site power source	$39,000	>$25,000,000	$27,000	$42,000	$17,000	$39,000	$43,000
AC/DC -22	Implement underground off-site power lines	$39,000	>$25,000,000	$27,000	$42,000	$17,000	$39,000	$43,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
AC/DC -24	Create the ability to automatically transfer battery charger/eliminator 2D31B to an alternate power source	$34,000	>>$34,000	$23,000	$37,000	$15,000	$35,000	$38,000
AT-01	Provide alternative ATWS pressure relief valves	$140,000	$1,000,000	$96,000	$151,000	$62,000	$140,000	$154,000
AT-02	Create a boron injection/shutdown system to backup the mechanical control rods	$140,000	$300,000	$96,000	$151,000	$62,000	$140,000	$154,000
AT-03	Provide a diverse plant protection system	$140,000	$3,000,000	$96,000	$151,000	$62,000	$140,000	$154,000
CB-01	Institute a maintenance practice to perform a 100% inspection of steam generator tubes during each refueling outage	$25,000	$1,500,000	$21,000	$29,000	$12,000	$25,000	$26,000
CB-03	Increase the pressure capacity of the secondary side	$25,000	>>$25,000	$21,000	$29,000	$12,000	$25,000	$26,000
CB-04	Install a redundant spray system to depressurize the primary system during a steam generator tube rupture	$25,000	$5,000,000	$21,000	$29,000	$12,000	$25,000	$26,000
CB-07	Provide main steam safety valve and automatic depressurization valve scrubbing	$178,000	$9,500,000	$178,000	$226,000	$91,000	$178,000	$178,000
CB-08	Provide additional steam generator tube rupture coping features	$25,000	>>$25,000	$21,000	$29,000	$12,000	$25,000	$26,000
CB-10	Direct steam generator flooding after a steam generator tube rupture, prior to core damage	$25,000	$35,000	$21,000	$29,000	$12,000	$25,000	$26,000
CB-13	Install additional instrumentation for interfacing system LOCA sequences	$86,000	$2,300,000	$78,000	$104,000	$42,000	$87,000	$90,000
CB-14	Increase frequency of valve leak testing	$86,000	>$86,000	$78,000	$104,000	$42,000	$87,000	$90,000
CB-19	Ensure all interfacing system LOCA releases are scrubbed	$86,000	>>$86,000	$78,000	$104,000	$42,000	$87,000	$90,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
CB-20	Add redundant and diverse limit switch to each containment isolation valve	$86,000	$1,000,000	$78,000	$104,000	$42,000	$87,000	$90,000
CB-23	Develop enhanced procedures for station blackout to prevent containment bypass	$200	$35,000	$100	$200	$100	$200	$200
CB-26	Enhance plant procedures to improve credit for human action to prevent and cope with an interfacing system LOCA	$64,000	>$70,000	$57,000	$77,000	$31,000	$64,000	$66,000
CC-01	Provide capability for diesel-driven, low pressure vessel makeup	$632,000	>$632,000	$436,000	$686,000	$282,000	$638,000	$699,000
CC-02	Provide an additional high pressure injection pump with independent diesel		$5,000,000	$436,000	$686,000	$282,000	$638,000	$699,000
CC-07	Extend the reactor water storage tank source	$632,000	$1,000,000	$436,000	$686,000	$282,000	$638,000	$699,000
CC-14	Replace two of the four electric safety injection pumps with diesel-powered pumps	$632,000	$2,000,000	$436,000	$686,000	$282,000	$638,000	$699,000
CC-18	Modify the containment sump strainers to prevent plugging	$36,000	>>$36,000	$21,000	$37,000	$15,000	$36,000	$41,000
CC-19	Provide an additional flow path from the refueling water tank to the high-pressure safety injection system through a diversified suction flow path check valve	$29,000	>>$29,000	$19,000	$31,000	$13,000	$30,000	$33,000
CC-20	Make containment sump recirculation outlet valve motor-operated valves 2CV-5649-1 and 2CV-5650-2 diverse from one another	$31,000	>$31,000	$20,000	$33,000	$14,000	$32,000	$35,000
CC-21	Provide actuator diversity for the motor-operated valves in the high-pressure safety injection system	$22,000	>$22,000	$14,000	$23,000	$10,000	$22,000	$25,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
CC-22	Incorporate diversity among recirculation actuation signal and engineered safety features actuation signal actuation relays	$15,000	>$15,000	$10,000	$16,000	$7,000	$15,000	$17,000
CC-23	Provide an additional recirculation actuation signal level transmitter (2LT-5636-5) and change recirculation actuation logic from 2-out-of-4 to 2-out-of-5	$5,000	>$5,000	$3,000	$5,000	$2,000	$5,000	$5,000
CC-24	Provide bypass flow paths for all safety injection tanks	$4,000	>>$4,000	$3,000	$4,000	$2,000	$4,000	$5,000
CW-01	Cap downstream piping of normally closed component cooling water drain and vent valves	$112,000	>$112,000	$73,000	$119,000	$49,000	$113,000	$125,000
CW-06	On loss of essential raw cooling water, proceduralize shedding component cooling water loads to extend the component cooling water heatup time	$25,000	$35,000	$16,000	$27,000	$11,000	$26,000	$28,000
CW-07	Increase charging pump lube oil capacity	$12,000	>>$12,000	$9,000	$14,000	$6,000	$13,000	$14,000
CW-09	Provide an additional diversified service water pump	$202,000	>$202,000	$139,000	$219,000	$90,000	$204,000	$224,000
CW-10	Create an independent reactor coolant pump seal injection system, with dedicated diesel	$71,000	>>$71,000	$48,000	$76,000	$31,000	$72,000	$79,000
CW-11	Create an independent reactor coolant pump seal injection system, without dedicated diesel	$71,000	>>$71,000	$48,000	$76,000	$31,000	$72,000	$79,000
CW-13	Replace emergency core cooling system pump motors with air cooled motors	$202,000	>$202,000	$139,000	$219,000	$90,000	$204,000	$224,000
CW-14	Install improved reactor coolant pump seals	$71,000	$2,500,000	$48,000	$76,000	$31,000	$72,000	$79,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
CW-15	Install an additional component cooling water pump	$76,000	>>$76,000	$51,000	$82,000	$34,000	$77,000	$85,000
CW-21	Implement procedure and operator training enhancements for support system failure sequences, with an emphasis on anticipating problems and coping	$25,000	$35,000	$16,000	$27,000	$11,000	$26,000	$28,000
CW-22	Improve ability to cool residual heat removal heat exchangers	$76,000	$565,000	$51,000	$82,000	$34,000	$77,000	$85,000
CW-23	Develop enhanced procedures for loss of service water	$25,000	$35,000	$16,000	$27,000	$11,000	$26,000	$28,000
CW-24	Provide the ability to automatically trip the reactor coolant pumps on a loss of component cooling water	$71,000	>$71,000	$48,000	$76,000	$31,000	$72,000	$79,000
CW-25	Add redundant control valve in series with 2CV-1530-1	$10,000	>$10,000	$7,000	$11,000	$4,000	$10,000	$11,000
CW-26	Increase inspections of service water pump discharge filters	$100,000	>$100,000	$68,000	$108,000	$44,000	$101,000	$111,000
CW-27	Replace current service water pump discharge strainers with backwash filters	$100,000	>$200,000	$68,000	$108,000	$44,000	$101,000	$111,000
EV-02	Install automatic containment spray pump header throttle valves	$178,000	$375,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-04	Develop an enhanced drywell spray system	$178,000	$1,500,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-05	Provide a dedicated drywell spray system	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-07	Install a filtered containment vent	$178,000	$5,700,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-08	Install an unfiltered containment vent	$178,000	$3,100,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-09	Create/enhance hydrogen control system with independent power supply	$178,000	$1,000,000	$178,000	$226,000	$91,000	$178,000	$178,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
EV-10	Create a passive hydrogen control system	$178,000	$800,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-11	Create a refractory-lined crucible with heat removal potential under the basemat to contain molten debris	$178,000	$108,000,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-12	Create a water cooled rubble bed on the pedestal	$178,000	$19,000,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-15	Create a reactor cavity flooding system	$17,000	$8,750,000	$14,000	$20,000	$8,000	$17,000	$18,000
EV-16	Creating other options for reactor cavity flooding (Option 1)	$17,000	>>$17,000	$14,000	$20,000	$8,000	$17,000	$18,000
EV-17	Creating other options for reactor cavity flooding (Option 2)	$17,000	>>$17,000	$14,000	$20,000	$8,000	$17,000	$18,000
EV-19	Provide a core debris control system	$178,000	$45,000,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-20	Create a core melt source reduction system (COMSORS)	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-21	Provide containment inerting capability	$178,000	$10,900,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-22	Use fire water spray pump for containment spray	$178,000	$565,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-23	Install a passive containment spray system	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-25	Increase containment design pressure	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-26	Provide an alternative concrete composition in the reactor cavity	$178,000	$5,000,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-27	Provide a reactor vessel exterior cooling system	$178,000	$2,500,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-28	Create a vacuum building	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000
EV-29	Add ribbing to the containment shell	$178,000	>>$178,000	$178,000	$226,000	$91,000	$178,000	$178,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
EV-30	Provide actuator diversity for motor-operated valves in the containment spray system	$38,000	>$38,000	$25,000	$40,000	$17,000	$38,000	$42,000
EV-31	Remove reactor vessel cavity check valve 2BS-46 internals	$17,000	>$17,000	$14,000	$20,000	$8,000	$17,000	$18,000
FW-01	Install a digital feedwater upgrade	$112,000	>$112,000	$73,000	$119,000	$49,000	$113,000	$125,000
FW-08	Provide hookup for portable generators	$5,000	>>$5,000	$3000	$5,000	$2,000	$5,000	$5,000
FW-13	Install an independent diesel for the condensate storage tank makeup pumps	$104,000	$271,000	$69,000	$111,000	$46,000	$105,000	$116,000
FW-15	Create passive secondary side coolers	$632,000	>$632,000	$436,000	$686,000	$282,000	$638,000	$699,000
FW-17	Enhance emergency feedwater flow control in the emergency operating procedures	$17,000	$35,000	$10,000	$17,000	$7,000	$17,000	$19,000
FW-18	Replace current pilot operated relief valves with larger ones such that only one is required for successful feed and bleed	$632,000	$2,700,000	$436,000	$686,000	$282,000	$638,000	$699,000
FW-19	Create ability to automatically align emergency feedwater/auxiliary feedwater suction to the other condensate storage tank on low-low level of 2T-41A or 2T-41B	$10,000	>>$10,000	$7,000	$11,000	$5,000	$11,000	$12,000
HV-03	Develop enhanced procedures for temporary HVAC	$174,000	>$300,000	$120,000	$189,000	$78,000	$176,000	$193,000
HV-05	Create ability to switch fan power supply to station batteries in a station blackout	$104,00	$226,000	$69,000	$111,000	$46,000	$105,000	$116,000
IA-02	Replace current air compressors with more reliable models	"minimal"	>>"minimal"	"minimal"	"minimal"	"minimal"	"minimal"	"minimal"
OT-02	Create a reactor coolant depressurization system	$632,000	$4,600,000	$436,000	$686,000	$282,000	$638,000	$699,000

Table E.2-2, Sensitivity Analysis Result (continued)

SAMA ID	Potential Enhancement	Estimated Benefit (baseline)	Estimated Cost	Estimated Benefit (Sensitivity 1)	Estimated Benefit (Sensitivity 2)	Estimated Benefit (Sensitivity 3)	Estimated Benefit (Sensitivity 4)	Estimated Benefit (Sensitivity 5)
OT-06	Install secondary side guard pipes up to the main steam isolation valves	$632,000	$1,100,000	$436,000	$686,000	$282,000	$638,000	$699,000
OT-07	Provide digital large break LOCA protection	$24,000	>>$24,000	$16,000	$26,000	$11,000	$25,000	$27,000