# Does a Safety-Class Active Ventilation System Significantly Enhance Safety?

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## Introduction

The estimation of risk or the change in risk has been an accepted addition to traditional nuclear safety analysis for many years. Large-scale risk assessments such as the *Reactor Safety Study*[1] and the 1991 Nuclear Regulatory Commission (NRC) study of five nuclear power plants[2] were performed to increase our understanding of severe accidents in nuclear power plants and to serve as companions to the regulatory framework already in place. The use of risk assessments can serve as a model for similar analyses in the U.S. Department of Energy (DOE) nuclear safety framework. Nuclear facilities are required to meet DOE nuclear safety criteria, including ensuring adequate protection to the environment, facility workers, and the offsite public. Safety analysis is crucial to new facility design considerations and to existing facilities that are contemplating modifications or system upgrades. When considering the alternatives to achieving the necessary protection required by DOE, risk impact can be one key input to making informed decisions. It can also serve as the basis for examining risk/cost-benefits.

In this paper, an evaluation of safety strategies was performed by examining the relative change in facility risk with an emphasis on the impact of safety-class active ventilation. Facility-specific results are presented from a risk-reduction study of a hypothetical new facility and for an existing plutonium-processing facility. A generic evaluation of risk that concentrates on key attributes of the specific analysis is also presented to provide a basis for more generalized results, as well as some general insights into risk/cost-benefit analysis.

## Methodology for Estimation of Risk

Risk as it is traditionally defined is an expression of possible loss that considers both the probability that an event will occur and the consequences of that event in quantitative value or qualitative expression. Therefore, risk will be defined here as the product of frequency expressed as the expected annual occurrence of an event times consequence. The consequence will be expressed as either a qualitative description of the accident scenario (such as a large unfiltered release) or as the population dose expressed in terms of latent cancer fatalities. (In one example it will be expressed as the dose to the maximally exposed offsite individual [MEOI], although this is not a true measure of consequence because the MEOI is hypothetical.)

Note that one rarely has available in the DOE nuclear safety field an integrated risk assessment that looks at all initiating events and then sums risk over a range of possible outcomes. As a surrogate measure of risk, this paper examines the design-basis accidents (DBAs) associated

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[1] Rasmussen, N. et al., *Reactor Safety Study*, WASH-1400, Washington DC: U.S. NRC, 1975.
[2] Nuclear Regulatory Commission, *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, U.S. NRC, 1991.

with a facility. The authors assume that risk can be evaluated relatively among each individual accident and use the total risk of each DBA as an estimate of the total risk of the facility.

## Definition of Safety-Class Active Ventilation

For purposes of this paper, the definition of *safety-class active ventilation* will be based on the criteria listed in the *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2004-2* produced by the Department of Energy.[3] These criteria indicate that the only difference between safety-significant and safety-class ventilation is in the area of single-point failure criteria. This implies reliability would be enhanced by eliminating single-point failures and including redundancy for key components such as electrical power or damper control. These same assumptions will be made in this paper. Therefore, the key element of a safety-class active ventilation system is its enhanced reliability from increased redundancy and the elimination of single-point failures.

## New Nuclear Facility Evaluation

For a new facility, systems can be designed using the benefit of lessons learned from previous operational experience and facility safety analyses. Cost considerations must be included in facility design and tradeoff studies. For this hypothetical new facility, a risk evaluation was conducted that looked at several nuclear safety strategies, including the following three cases:

1. a passive confinement strategy with a safety-class confinement;
2. a safety-class active ventilation strategy (HVAC and facility boundary); and
3. a passive confinement strategy, with safety-class fire barriers and fire suppression system. Active ventilation is left as safety-significant.

In this example, three event trees (Figures 1 through 3) were developed for a hypothetical fire that could spread to include the whole facility. Cases 1 through 3 above were evaluated separately. The event trees are used to compare the frequency of events based on the ability of the systems to perform their intended safety functions and the end-state of each path in the tree. This end-state can be viewed as a qualitative measure of consequence and binned into categories of similar consequence.

In the trees, some assumptions must be made on the availability of each control. For this example, the conditional probability of each system being available to perform its intended function was taken from Table T6-2A and 6-2B of the Implementation Plan.[3] A basic assumption in the trees is that if the fire spreads beyond a single room and becomes a large facility-wide fire, the active ventilation will be overcome by the size of the fire.

By examining the trees, one gains the following insights:

- The added availability of safety-class active ventilation lowers the frequency of *No Confinement* by an order of magnitude. However, it should be noted that the frequency was already beyond extremely unlikely.

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[3] U.S. DOE, *Deliverables 8.5.4 and 8.7 of Implementation Plan for DNFSB Recommendation 2004-2, Ventilation System Evaluation Criteria for Safety-Related and Non-Safety-Related Systems,* January 2006, Rev. 0.

- The availability of active ventilation is still very high with a safety-significant ventilation system versus a safety-class ventilation system.
- The *Large Fire, Large Release* end-state has the same frequency as the *No Confinement* end-state, but it is of more concern. This end-state occurs when a fire spreads to the entire facility, and thus could provide a larger consequence (i.e., it may involve more material-at-risk [MAR], with no ability to mitigate the release). Safety-class ventilation does not change its frequency, but it can be lowered dramatically (by possibly two orders of magnitude) by improving the reliability of the fire barriers and fire suppression system.

A conclusion that can be drawn from this simple example is that more risk reduction (i.e., the lowering of frequency for end-states with higher qualitative consequences) can be obtained by looking at all possible combinations of safety systems. In this example, the best means of lowering risk is through improvements in reducing the spread of fire and not by simply improving the availability of active ventilation. This example also does not examine the cost of upgrading each system to safety-class. When cost is included, improvements to fire barriers and fire suppression become even more attractive. Costs of fire barriers and fire suppression systems are estimated to be in the tens of millions of dollars compared to hundreds of millions of dollars for active ventilation systems.

## Existing Nuclear Facility Evaluation

Another example is the evaluation of an existing facility, in this case an operating plutonium-processing facility. Included in this evaluation were comparisons of the costs and the potential relative reduction of offsite doses for various facility modifications. (Note that in this example only reduction in consequence is evaluated [not the reduction in risk] and consequence is taken to be the MEOI dose.) In total, eleven unique modifications were evaluated, including an upgrade of active ventilation to safety-class and other upgrades such as improving the seismic capacity of gloveboxes. Complete descriptions of the modifications are given in a Los Alamos National Laboratory (LANL) submittal to DOE.[4] Each modification was assessed against a set of postulated accident scenarios in the facility's Documented Safety Analysis (DSA) that had the highest mitigated offsite doses, using the current confinement ventilation strategy.

Following the guidance in the Implementation Plan,[3] a semi-quantitative approach was employed to evaluate the impact on offsite doses from the potential modifications. Offsite doses were the exclusive risk parameter considered, because the facility DSA only addresses offsite dose and not integrated risk. For this evaluation, the unmitigated dose is divided by the mitigated dose for each facility modification for each accident. A simple summation of these ratios is then performed to obtain a single number for each option. The difference between the baseline (current facility configuration) number and the option numbers gives the expected benefit for each option. The expected benefit is a dimensionless number and can be used for relative comparisons of the options. The results are presented graphically in Figure 4.

In the figure, the bars represent the relative benefit, as described above, for each modification. The diamonds that are superimposed on the bars are the offsite doses for the seismic event with fire (the largest consequence event). The values representing the estimated costs for each

[4] LANL memo to R. Nelson, "PF-4 Ventilation System Evaluation, Submittal," FOD/ENG-TA-55: (U): 06-003, Nov. 14, 2006.

modification appear below the x-axis. As shown, many of the modifications, including the safety-class ventilation, do not reduce the dose as much as some less costly modifications such as upgrading the seismic capacity of gloveboxes. Note also that the safety-class ventilation system has essentially the same *benefit* as seven other modifications, all of which have lower costs. One can conclude that in this risk/cost-benefit analysis, safety-class active ventilation may not produce the optimum solution in terms of risk (or in this case, consequence)/cost-benefit tradeoff.

The conclusion again is that when measuring risk reduction (even when it only includes consequences and not frequency), all systems must be included. In this evaluation more risk reduction or equivalent risk reduction could be obtained for lower cost (in this case dramatically lower cost) than for a safety-class ventilation system.

## Generic Evaluation of Risk

Studies of DOE nuclear facilities have shown that the vast majority of risk from accidents in the facilities comes from fires and seismic events. (At the LANL Plutonium Facility, these two types of events account for 98% of the risk stated in terms of latent cancer fatalities per year.[5]) Thus, an evaluation of the effectiveness of any control to improve DOE nuclear facility safety should concentrate on fires and seismic events. These are the two events that potentially release the most radioactive MAR to the environment and consequently result in the largest potential doses to the public.

The two previous sections presented specific examples of why safety-class active ventilation does not tend to reduce risk very much relative to other potential safety controls. It may be more instructive to examine more generically the impact that having safety-class active ventilation can have on the two dominant accident events, namely fire and seismic events.

For a fire event, the main advantage of a safety-class active ventilation system is that it derives increased reliability from the elimination of single-point failures and increased redundancy. However, during a typical fire event in a nuclear facility, very rarely is the fire in a location to impact the reliability of the system and also impact MAR (i.e., the MAR is in a different location than the fans or power source that the fire could impact, rendering the system inoperable). This means that the only risk reduction available is that obtained from taking an already very reliable system and further improving its reliability. Said another way, the risk that is removed is based on the random failure of the ventilation system coincident with the fire occurring. Clearly, this is a very low frequency event and one that typically does not contribute heavily to the overall risk of fire at a DOE nuclear facility. This also gives insight into how other safety systems such as fire suppression systems and fire barriers can possibly lower risk significantly, given that they typically are present in the room of fire origin and their reliability is more directly related to the presence of the fire.

For seismic events the ability of a safety-class active ventilation system appears to offer more risk reduction, although perhaps not as much as other approaches. Two issues arise when examining safety-class ventilation for seismic events. The first centers on total risk and the issue

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[5] Holderness, J., *Risk-Reduction Benefits of Proposed Upgrades at the Plutonium Facility (PF-4),* SSI-TR-001, Rev. 1, Jan. 30, 2006.

that we only examine up through a design-basis event. In actuality, much of the facility risk lies in the beyond-design-basis event. For example, for the LANL Plutonium Facility, seismic events make up 83% of the total facility risk. The beyond-evaluation-basis earthquake alone accounts for 77% of that risk.[5] Therefore, any upgrade may have limited ability to impact total risk. The second goes back to previous issues with fire. Making ventilation better able to handle seismic events clearly can impact this set of events by reducing offsite doses. However, it still can be outperformed in terms of risk reduction by safety controls that eliminate the release of material by preventing a spill during a seismic event. Items such as shelving and containers (which prevent releases and not just mitigate them) typically perform better generically in this area than an upgraded ventilation system.

## SEN-35-91 and Risk/Cost-Benefit

If the risk reduction for safety-class active ventilation were comparable to other proposed nuclear safety features, then the final argument against placing too much emphasis on active ventilation would be the cost. Estimates for a robust, active safety-class ventilation system are in the hundreds of millions of dollars.[6] Even small upgrades to the ventilation system that do not necessarily cover all aspects of a safety-class ventilation system are estimated to be in the tens of millions of dollars. When one compares these costs to the cost of other safety features, which can be in the tens of millions of dollars, one can understand why an active ventilation system does not fare well in risk/cost-benefit comparisons.

One avenue that DOE recently suggested to examine the need for upgrades to active ventilation (to better approach or attain safety-class) is to use the same approach used by the NRC for proposed backfits to nuclear power plants. This involves numerical estimates of benefit using dollar values for averted latent cancer fatalities to the public. This approach does not justify such expensive upgrades as active ventilation.

To evaluate the maximum benefit that could be derived in a risk/cost-benefit analysis, one can take as the maximum acceptable risk the value set as a goal by James Watkins, DOE Secretary of Energy, in the Department's *Nuclear Safety Policy*.[7] The policy sets the goal of risk to not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risk resulting from all other causes. In many documents, including the DOE safety survey,[8] the value for cancer fatalities is about 2E-3 cancer fatalities per year as the individual risk from all causes. This provides a value of 2E-6 cancer fatalities per year as the DOE safety goal. If one then assumes some nominal value for the population affected (100,000 people inside the 10-mile radius), a nominal dollar value for a latent cancer fatality ($5 million,[9] which is roughly the NRC value),

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[6] A current estimate for upgrading the Los Alamos Plutonium Facility to safety-class is well in excess of $300 million.

[7] Watson, J., *Nuclear Safety Policy,* SEN-35-91, Sept. 9, 1991, states: "The risk to the population for cancer fatalities which might be attributed to the operations of a DOE nuclear facility should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within 10 miles of the site boundary."

[8] Pinkston, D., *U.S. Department of Energy, Defense Programs, Safety Survey Report, Volume 1,* SAIC for DOE, November 1993, Contract No. DE-AC01-92DP70056.

[9] NUREG-1530, *Assessment of NRC's Dollar Per Person-Rem Conversion Factor Policy,* 1995, assuming $2000 per rem and a 2000 person-rem equaling a latent cancer fatality (value rounded up to $5 million to account for inflation).

and an assumption on the years of facility life (assumed to be 50 years), then the maximum benefit is

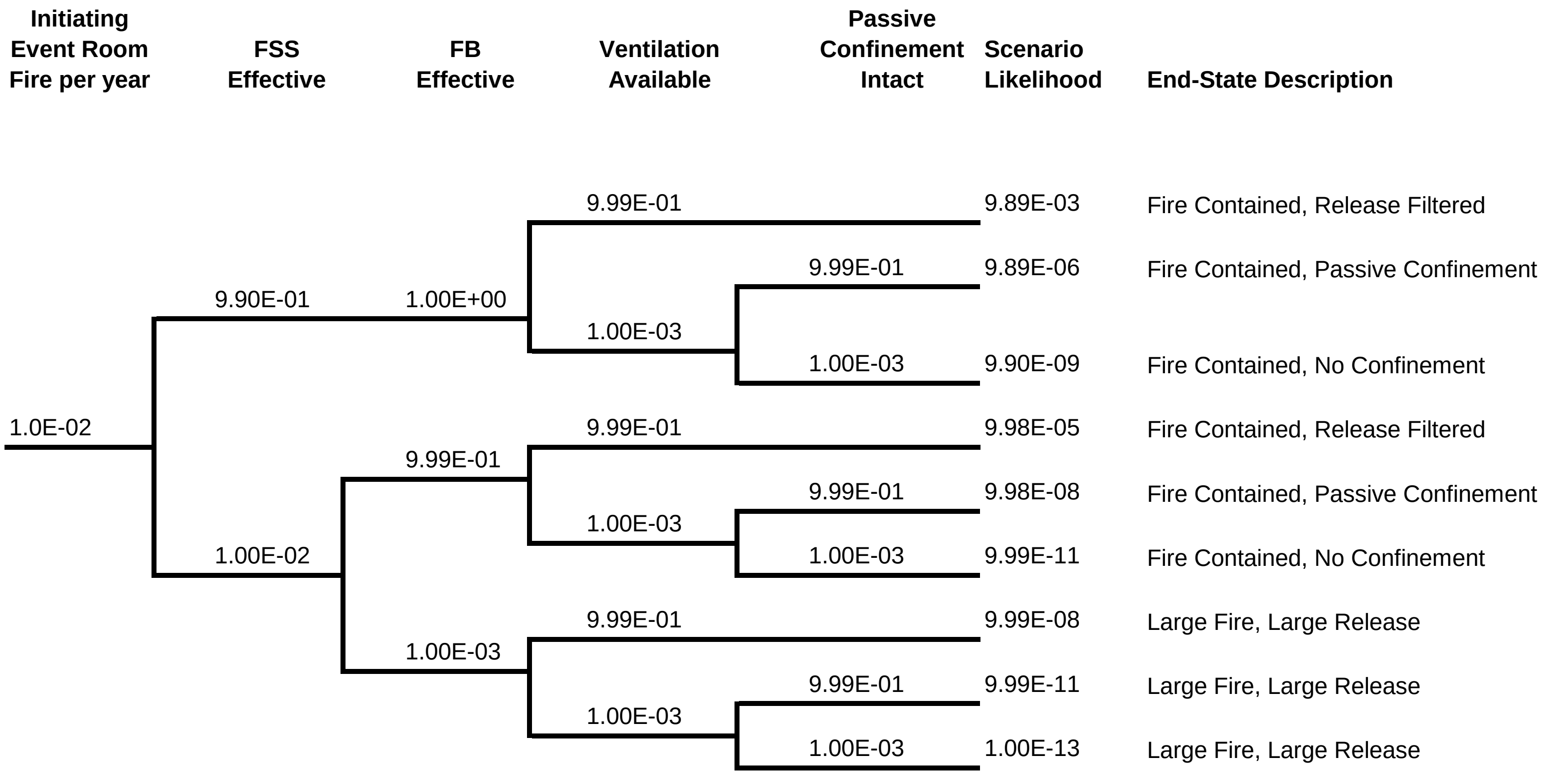
$$\begin{aligned} \text{Max benefit} &= \text{2E-6 cancers per year per person} \times \text{100,000 people} \\ &\times \text{\$5 million per latent cancer} \times \text{50 years} \\ &= \text{\$50 million} \end{aligned}$$

This argument is presented because most DOE facilities have risks that are several orders of magnitude (about a factor of 100) below the DOE safety goal (see the DOE safety survey[8] for examples). The risks are much smaller because the consequences for DOE facilities are in most cases thousands of times smaller than that for commercial nuclear power plants. This means that the dollar value of public consequences is in the $500,000 range. In reality, you cannot justify upgrades in the tens or hundreds of millions of dollars if the benefit of cancer fatalities averted is your measure. In most DOE facilities, upgrades for active ventilation of any substantial nature usually are well into the tens or hundreds of millions of dollars.

## Conclusions

Using examples of new and existing facilities, it has been shown under many circumstances that safety-class ventilation systems may not always significantly enhance safety by significantly lowering risk by itself. The lesson from these examples is that it may take the totality of potential safety systems (e.g., fire barriers, fire suppression systems, containers, seismically qualified shelving, gloveboxes) to ensure that risk is most effectively reduced and in particular reduced in the most cost-effective manner. Relying too heavily on a single system to assure nuclear safety has historically not been an effective approach.

CASE 1 - Safety Class Passive Confinement Only



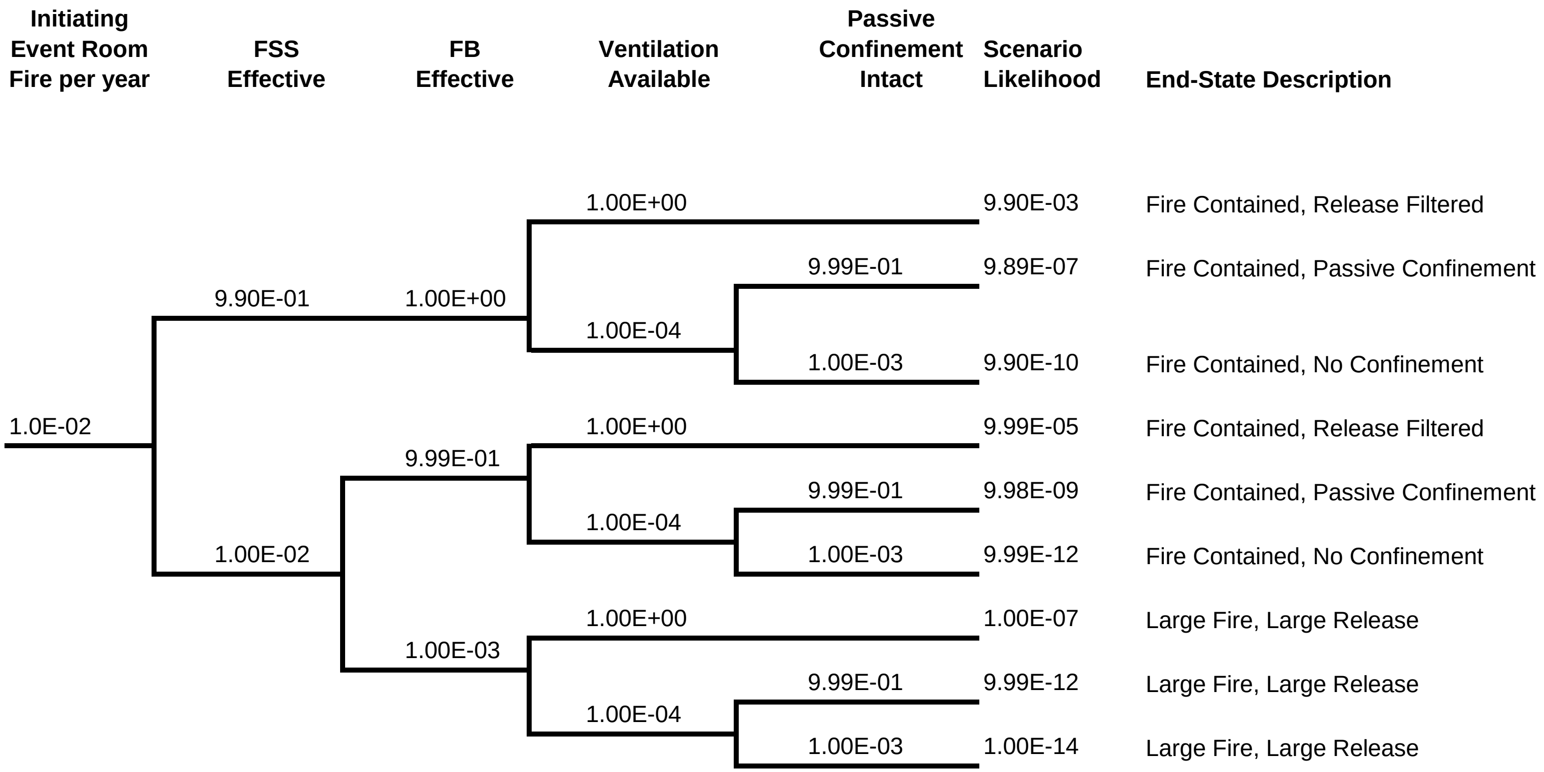

Sum of Large Release End States
1.00E-07
Sum of No Confinement End States
1.00E-08
Sum of Fire Contained, Passive
9.99E-06
Sum of Fire Contained, Release filtered
9.89E-03

Prob Failure from Ventilation System Guidance (T6-2A and 6-2B)

| | | Pf |
|---|---|---|
| Fire Suppresion System | SS | 1.E-02 |
| Fire Barriers | SS | 1.E-03 |
| Active Ventilation System | SS | 1.E-03 |
| Passive Confinement | SC | 1.E-03 |

Figure 1. Event tree with passive confinement as safety-class.

CASE 2 - Safety Class Active Ventilation and Safety Class Passive Confinement

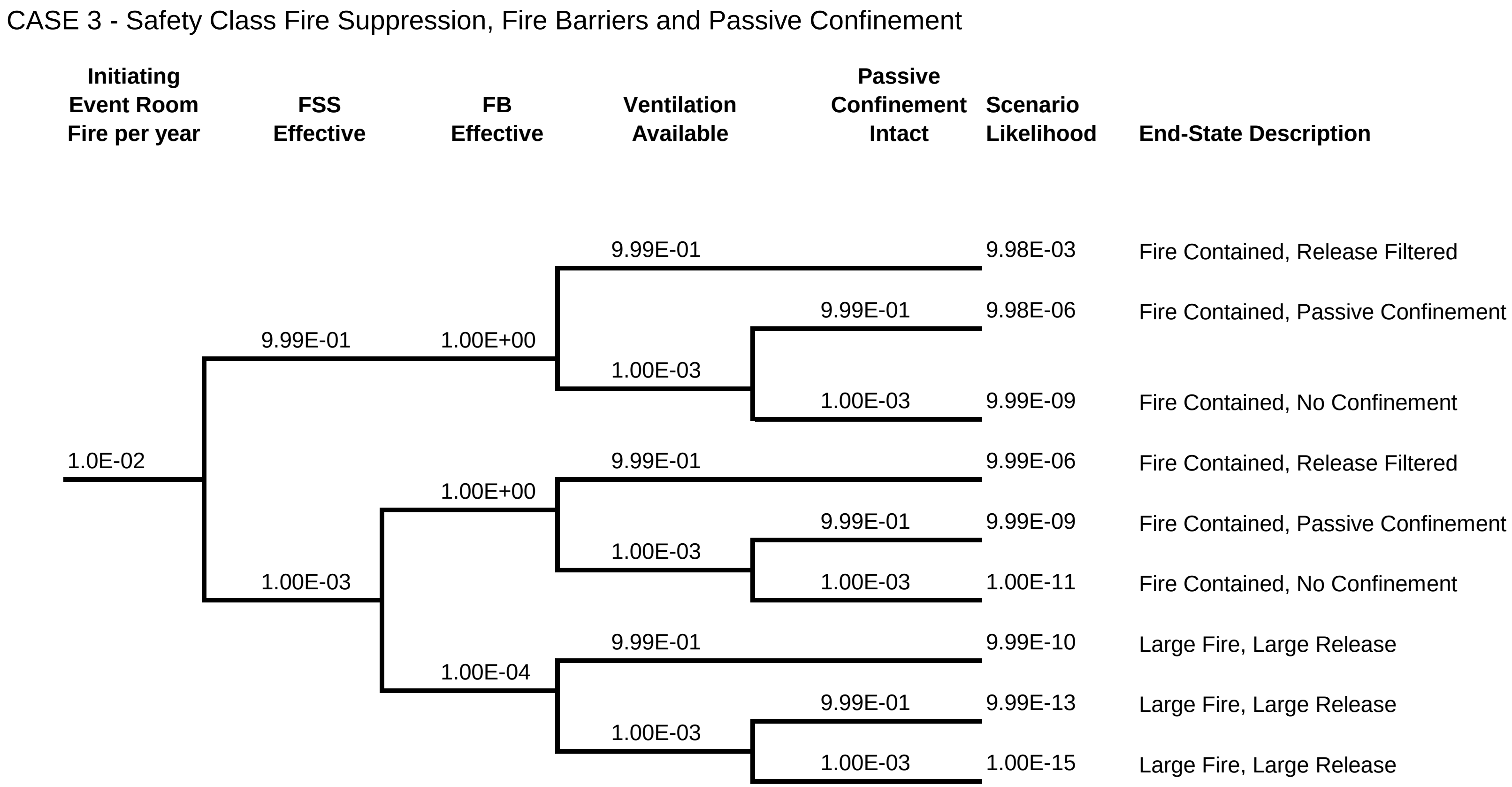



Sum of Large Release End States
1.00E-07
Sum of No Confinement End States
1.00E-09
Sum of Fire Contained, Passive
9.99E-07
Sum of Fire Contained, Release filtered
9.90E-03

Prob Failure from Ventilation System Guidance (T6-2A and 6-2B)

| | | Pf |
|---|---|---|
| Fire Suppresion System | SS | 1.E-02 |
| Fire Barriers | SS | 1.E-03 |
| Active Ventilation System | SC | 1.E-04 |
| Passive Confinement | SC | 1.E-03 |

Figure 2. Event tree with active ventilation and passive confinement as safety-class.




Sum of Large Release End States
1.00E-09
Sum of No Confinement End States
1.00E-08
Sum of Fire Contained, Passive
9.99E-06
Sum of Fire Contained, Release filtered
9.98E-03

Prob Failure from Ventilation System Guidance (T6-2A and 6-2B)

| | | Pf |
|---|---|---|
| Fire Suppresion System | SC | 1.E-03 |
| Fire Barriers | SC | 1.E-04 |
| Active Ventilation System | SS | 1.E-03 |
| Passive Confinement | SC | 1.E-03 |

Figure 3. Event tree with fire barriers, fire suppression system, and confinement as safety-class.

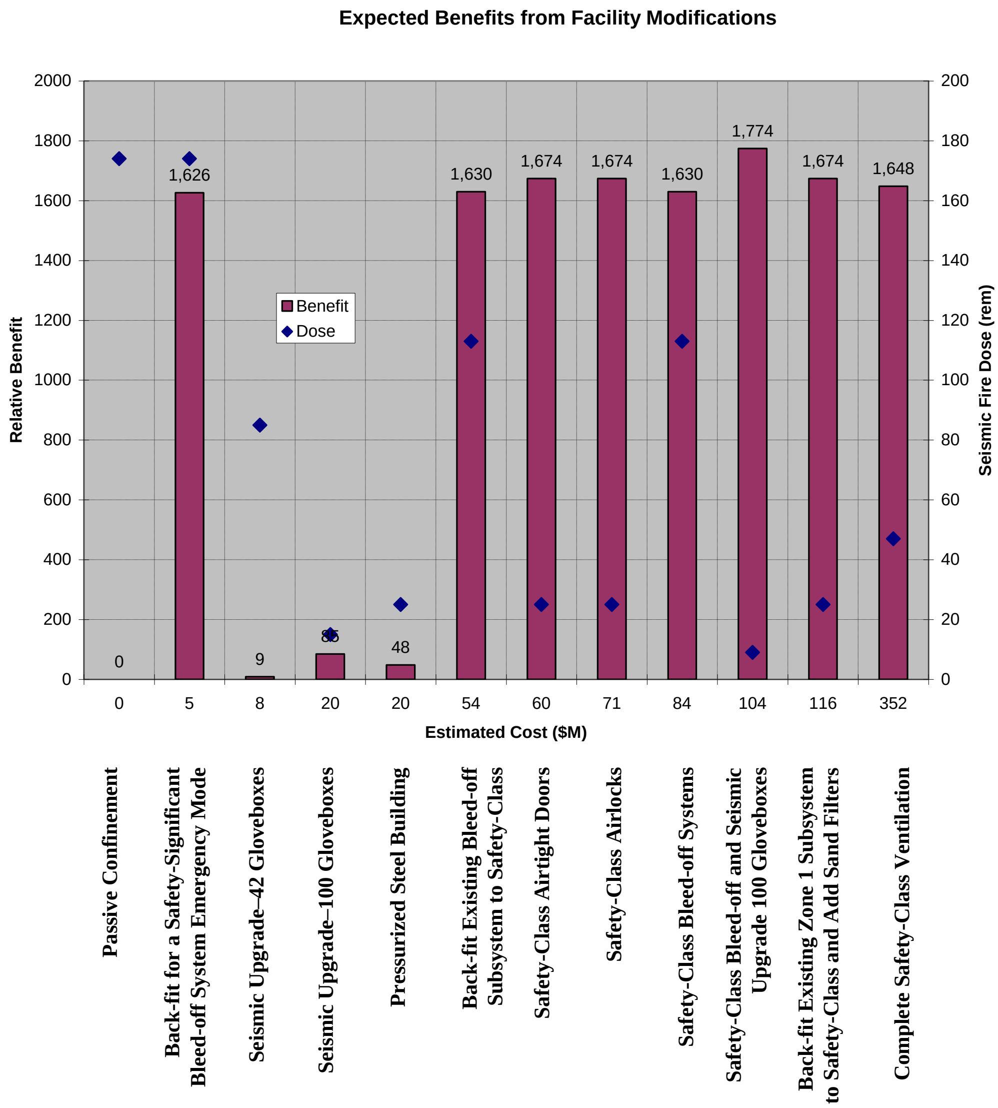



Figure 4. Expected benefits of potential LANL plutonium facility modifications as a function of cost.