# EFCOG Best Practice # 265

**Facility:** EFCOG Nuclear and Facility Safety (NFS), Safety Basis, Hazard Analysis Task Group

**Best Practice Title:** Best Practices Using Filters and Air Cleaning Devices for Risk Reduction in Hazard Analyses Supporting the Documented Safety Analysis for Nuclear Facilities

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**Brief Description of Best Practice:** This Best Practices provides a cohesive approach for improved processes used in nuclear facilities regarding use of filters and related air cleaning devices for risk reduction in Hazard Analysis (HA) and Accident Analysis (AA) documentation supporting the Documented Safety Analysis (DSA). Best Practices may also be appropriate for below hazard category 3 radiological and nonnuclear facilities.

**Why the Best Practice Was Used:** Develop a cohesive control strategy for the HA and AA process with respect to credited controls, safety functions, functional requirements, and performance criteria. Incorporating new technologies into the HA and AA process can achieve significant successes in risk reduction, lifecycle cost reduction, and improvements in safety to receptors (i.e., public, collocated worker, environment). The approaches and lessons learned, are suitable for Department of Energy (DOE) Complex-wide application. This Best Practice provides technical justification in support of DOE-STD-1269, *Air Cleaning Systems in DOE Nuclear Facilities*, and DOE-HDBK-1169, *Nuclear Air Cleaning Handbook*.

**What the Benefits of the Best Practice Are:** This cohesive approach utilizes new and existing technologies within the HA and AA control strategy to support the DSA. Benefits include risk reduction, lifecycle cost reduction, cohesive control suite throughout the HA, AA, and DSA, and improvements in safety to receptors. This Best Practice provides examples of how advances in technology can be implemented in the safety basis community, and provides an overview of the safety analysis process (HA, AA, control derivation, DSA).

**What Problems/Issues Are Associated with the Best Practice:** High Efficiency Particulate Air (HEPA) filters degrade in many accident conditions (i.e., high temperatures, fires, flood) and sustained strength/filtration efficiency may decrease. Contact with water or burning embers can impact the functional capability of HEPA filter performance. HEPA filters can also degrade over time based on age, environment, usage, particulate loading, and exposure to moisture. By considering these limitations in the control derivation process in the HA and AA, the DSA is able to discuss the parameters whereby the filter(s) provide sufficient effluent reduction and protection of receptors. This Best Practice provides advances in development of a cohesive control strategy, throughout the HA, AA, and DSA process via credited controls, functional requirements, performance requirements, and incorporation of new technologies. This Best Practice highlights changes for consideration within new and updated HA, AA, and DSA processes.

**How the Success of the Best Practice is Measured:** This Best Practice highlights opportunities for significant risk reduction and lifecycle cost reduction by streamlining the HA, AA, and DSA control derivation process.

**Description of Process Experience Using the Best Practice:** By providing a cohesive control strategy throughout the HA, AA, and DSA process credited controls, functional requirements, performance criteria, and incorporation of new technologies can be attributed to success in risk reduction, lifecycle cost reduction, and improvements in safety to receptors.

– Appendix –

## 1. Introduction

This Best Practice provides a fresh perspective on the development of a cohesive approach to Hazard Analysis (HA), Accident Analysis (AA), and control suite selection (control derivation). This cohesive approach is built upon effective HA and AA processes, selection of appropriate Hazard Evaluation (HE) techniques, and defining a robust suite of credited controls, including functional requirements, performance requirements, surveillance requirements. By incorporating new technologies such as High Efficiency Particulate Air (HEPA) and other filtration systems, there can be significant success demonstrating risk reduction, lifecycle cost reduction, and improvements in safety to receptors. The approach used and lessons learned, demonstrate best practices suitable for complex-wide Department of Energy (DOE) application. This best practice provides technical justification in support of DOE-STD-1269, *Air Cleaning Systems in DOE Nuclear Facilities*, and DOE-HDBK-1169, *Nuclear Air Cleaning Handbook*.

### 1.1 Hazard Analysis Process

The HA process is comprised of two (2) steps: (1) Hazard Identification (HI); (2) Hazard Evaluation (HE). The HA process begins with a formal HI and screen(s), as deemed appropriate and applicable per the invoked Safe Harbor methodology. The HE technique (e.g., What-If, What-If/Checklist, HazOp[1], FMEA[2]) is selected based on the complexity and hazards of the process. The HE technique is then executed by a qualified facilitator to develop accident scenarios/events. The preliminary HE technique should utilize a broad-brush approach (i.e., What-If/Checklist) which encompasses the entire system (facility, activity, and/or operation). A more prescriptive technique (e.g., HazOp, FMEA, STPA[3]) may then be applied to a portion(s) of the system based on the results of the preliminary analysis, events which require more detailed analysis, and those events identified as Design Basis Accidents (DBAs) or Beyond Design Basis Accidents (BDBAs). Additional information on HE technique selection, screening criteria, and additional HA strategies can be found in the Center for Process Safety, *Guidelines for Hazard Evaluation Techniques, Third Edition* (Redbook); and DOE-HDBK-1163-2020, *Integration of Multiple Hazard Analyses*. Results from the HE yields a series of unmitigated accident scenarios/events.

### 1.2 Risk Analysis Process

For applications using risk (consequence x frequency[4]), an unmitigated consequence and unmitigated frequency is assigned for each accident scenario/event. An *acceptable* unmitigated consequence screen may be used to further reduce the number of accident scenarios/events which carry forward into the risk analysis process.

The next step is to consider the suite of controls, that when *credited* will prevent or mitigate the accident scenario/event to an acceptable risk. When applying risk, consequence levels, frequency levels, and risk levels must be defined prior to the initiation of the HA process. Unacceptable consequence and unacceptable risk levels must also be defined for accident scenarios/events. By defining unacceptable consequences and unacceptable risk, the acceptable (tolerable) consequences and acceptable (tolerable) risk are also defined. Starting from the unmitigated accident scenarios/events, begin applying controls to reduce the overall risk to an acceptable level.

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[1]Hazard and Operability Study (HazOp)

[2]Failure Modes and Effects Analysis (FMEA)

[3]Systems Theoretic Process Analysis (STPA)

[4]Frequency is synonymous with Likelihood

Risk applications may be qualitative, quantitative, or semi-quantitative/semi-qualitative in nature. When using quantitative techniques, controls must also be assigned a quantitative reduction value. When using a qualitative or semi-quantitative/semi-qualitative technique, controls may be assigned a qualitative or semi-quantitative/semi-qualitative reduction value; typically, a single "bin drop." The most common approaches in used in support of a Documented Safety Analysis (DSA) for Department of Energy (DOE) nuclear facilities are qualitative or semi-quantitative/semi-qualitative. The formal AA process may also utilize qualitative, quantitative, or semi-quantitative/semi-qualitative techniques. Controls are assigned a risk reduction level, which is used to either reduce the consequence (mitigative) or reduce the frequency (preventive) of an accident scenario/event.

Consult the risk matrix[5] to determine if the unmitigated risk for each accident scenario/event is acceptable or unacceptable. If unacceptable, then apply controls to decrease the frequency (preventive) or consequence (mitigative) for each accident scenario/event. Apply a qualitative, quantitative, or semi-quantitative risk analysis techniques to assign a mitigated frequency and mitigated consequence of each accident scenario/event. The risk matrix determines the value or importance of each credited control based on "bin drops," mitigated risk level, and residual risk. Personal protective equipment (PPE) should never be used as a DSA-level control; PPE should be managed by Safety Management Program (SMP) implementation. Further risk reduction may be provided in the form of Defense-in-Depth (DID) controls. Controls identified as DID are derived in a similar fashion as credited controls, the difference being "bin drops" remain within the acceptable risk level. Additional controls for consideration are those defined as defense-in-depth, which may be added to the control suite for a given set of accident scenarios/events, but have no "bin drop" value for risk reduction.

When performing a quantitative or semi-quantitative risk analysis, it is important to ensure the numerical reduction value is supported by data. This data documents the reduction value (e.g., "credit") assigned to a given control. The supporting data should provide a technical basis for the reduction and may include manufacture and test data.

## 1.3 Control Derivation Process

The suite of credited controls within the HA, AA, and DSA are a combination of preventive and mitigative, engineered and administrative controls. Controls which are preventive (frequency reducers) have precedence over mitigative controls (consequence reducers). Preventive controls are preferred over mitigative controls, passive controls are preferred over active controls, and engineering controls are preferred over administrative controls. Engineered controls are generally referred to as Structures, Systems, and Components (SSCs) and can be Safety Class (SC) or Safety Significant (SS) depending on the accident progression and receptors. For engineered controls, the analyst must consider several factors: (1) who/what the control is protecting; (2) how the control works; (3) what the control does; (4) how the control maintained/protected; (5) if the control is independent; (6) if failure of the control can initiate an accident or release. Both the safety function and performance criteria must be described in the HA and/or AA documentation with a greater level of detail provided in the DSA and Technical Safety Requirement (TSR) documentation. Surveillance requirements must also be defined to ensure the SSC maintains functionality above a minimum value ensuring risk reduction levels are preserved based upon the value provided to each control.

[5] Refer to the applicable Safe Harbor methodology for specific risk matrix guidelines and expectations.

## 2. Consideration of Potential Controls

When deliberating the suite of potential controls, filters and related air cleaning devices may be appropriate to consider for risk reduction in HAs and AAs, which support the DSA. Filters and air cleaning devices can vary in filtration efficiency, pressure drop, capabilities, and resilience to high temperatures, fires, moisture, and corrosive environments. Some examples of filter types used include HEPA, Ultra Low Penetrating Air (ULPA), ceramic HEPA filters, ceramic filters and pre-filters, metal HEPA filters, and high strength HEPA filters. Other examples of air cleaning devices may include activated carbon beds, bag houses, electrostatic precipitators, impingement, scrubber systems (adsorbent or absorbent media), and combination filters/scrubber units.

Technological advances with filters and air cleaning devices support their use as credited SSCs within HA, AA, and DSA documentation. When establishing numeric values for effluent reduction under a wide range of scenarios (normal or abnormal events), the reliability or performance of the filter should be more robust. This concept is especially pertinent when evaluating scenarios with the potential to expose filters and air cleaning devices to destructive conditions. The ability for filters and air cleaning devices to survive elevated temperatures during a fire, elevated moisture levels, fires, explosions, pressure pulses are all relevant to the technical basis for documenting potential risk reduction.

If adequately justified within the technical basis, a filter or air cleaning device may be assigned multiple safety functions. When controls possess multiple safety functions, associated performance criteria for each safety function must also be documented. In this case, a single control could be credited for multiple risk reduction aspects for different receptors. For example, a traditional (paper) HEPA filter may be credited for confinement barriers and protection of the ventilation system for the worker, while ignoring the potential credit for filtration of effluent to the collocated worker, public, or environment. When developing the control strategy within the HA, AA, and DSA, the analyst should consider and define the full capability of protection the control provides; not just the protection to the immediate worker.

### 2.1 Crediting Controls for Risk Reduction

Feeding from the HA and/or AA, the derivation of each control provides a given “value” in terms of “binning” and risk reduction. Meaning the likelihood (prevention) or consequence (mitigation) reduction. Use of this given “value” for controls yields a derived risk reduction in the HA process. The control derivation process requires an understanding of the entire risk structure. When selecting controls, consider both the preventative or mitigative function. A single control should not be assigned both a preventive and mitigative function for a single receptor, however a single control may provide a preventive or mitigative function for different receptors. When defining the technical basis for controls with both a preventive and mitigative aspect spanning across multiple receptors, ensure the limitations are defined surrounding the operational environment and potential accident conditions that may be encountered. This is important to ensure to the selected controls are adequately designed for a given environment.

### 2.2 Hazard Controls

In order to effectively utilize filters and air cleaning devices in the risk assessment process, to the analyst must first understand the hazards of the effluent (e.g., radiological, flammable, corrosive, toxic) along with the effluent concentrations. The analyst must consider secondary or indirect hazards with the ability to negatively impact potential controls (e.g., fires, moisture, corrosive environments).

The optimal suite of controls is "right sized" and addresses all hazards –particulates, effluents, fires, high temperatures, burning embers, moisture, corrosive environments, etc. The analyst must consider key attributes of the control required to perform the functional requirement against the system design with the overall objective to prevent hazardous material releases from a facility.

## 2.3 Control Requirements for Particulate Removal

The primary hazard of concern for an external release of radiological and/or other hazardous material as particulate through the facility stack. Filters are the primary control used to prevent the external release of particulate from a facility.

If a filter does not provide a uniformed filtration efficiency (e.g., 99.97%), then the level of filtration provided must be discussed in the technical basis when used as a "bin drop" control in the HA, AA, or DSA. The technical basis should discuss the quantifiable filtration efficiency of the control, and the "bin drop" should account for discrepancies between assumed efficiencies and actual efficiencies for quantitative or semi-quantitative risk discussions (e.g. a given filter may only be "credited" for a 90% filtration efficiency within he Safety Basis documentation). Although the assumed efficiency value may not reflect the 99/97% value, there is a measurable reduction of risk for the potential release of radiological or other hazardous material as particulate. When discussing the technical basis for risk reduction, the following approaches may be taken into consideration.

[1] If a ceramic filter is used as a pre-filter to protect a traditional (paper) HEPA filter, two (2) different safety functions may be discussed. (1) The safety function of the ceramic filter could protect the traditional HEPA filter in specific accident conditions (i.e., fire). (2) The traditional (paper) HEPA filter can perform the safety function of filtration for particle reduction (minimize consequence) to the non-facility worker receptor (i.e., collocated worker, public, environment). A single ceramic filter could perform multiple safety functions to (1) survive a fire and (2) provide filtration for particle reduction, thereby providing a more resilient approach to minimize consequences of hazardous and/or radiological material release during a fire.

[2] Using a series of filters with lower filtration efficiency (e.g., 99.9%) may provide equal or in some cases greater effluent reduction than a single higher filtration efficiency filter (e.g., 99.97%). For example, if 10,000 particles are released and utilize two filters in series, each with 99% filtration efficiency, only 1 out of 10,000 particles is released from the facility. In this example, the overall numerical filtration efficiency level is 99.99%, which is greater than the nominal efficiency value for a single HEPA filter (99.97%).

[3] In some cases, the use of a single filter may not provide sufficient effluent reduction for the potential worst-case release parameters. By using two (2) ceramic filters in series, each with 99% filtration efficiency, the safety function of the overall filtration system could survive a fire and continue to reduce airborne particulate releases by an overall 99.99% filtration efficiency.

## 2.4 Effluent Hazards

If filtration systems remove radiological material and do not address other hazardous characteristics, there is a potential the effluent concentrations will exceed regulatory thresholds for flammability, corrosivity, or even toxicity. In cases where the effluent remains toxic, there is a potential for toxic endpoints to reach or exceed emergency planning guidelines (i.e., PAC[6], AEGL[7], ERPG[8], TEEL[9]), Permissible Exposure Limits /Threshold Limit Values, or even Immediately Dangerous to Life and Health levels. To address these concerns, the safety analyst must understand not only the radiological component, but a holistic characterization of the entire effluent stream. Understanding the hazards of the effluent, design of the system, and how controls are being credited to mitigate the effluent release all play a vital role in selecting controls and documenting the technical basis for risk reduction to ensure hazards are adequately minimized.

## 2.5 Control Suite Optimization

For optimal control suite selection, consider specific effluents that are hazards themselves (e.g., corrosives) or hazards to controls (e.g., moisture damages traditional paper HEPA filters). Are additional controls available to mitigate these conditions? Are secondary controls needed to protect the safety function of controls credited for risk reduction? For example, traditional (paper) HEPA filters reduce the particulate levels released, but are vulnerable to high heat and fire conditions. Means to address this vulnerability could include the use of a sprinkler system (secondary control) on prefilter HEPA banks. Based on the technical basis for risk reduction, sprinklers (secondary control) could be necessary to protect traditional HEPA filters from fires. Because of the potential for damage when water is introduced to a traditional HEPA filter system, the need for multiple HEPA filter banks may be derived as part of the control structure and technical basis for risk reduction.

When optimizing controls, the analyst should explore the availability and feasibility for a single dedicated control to provide the necessary safety function. When selecting controls that require secondary or tertiary protection, the technical basis may become overly complex. When possible strive to design and define controls in a manner that does not require additional protection (i.e., fail safe) in accident conditions. For example, ceramic filters are designed to survive various accident conditions (e.g., elevated temperatures during a fire). Ceramic filters will continue to mitigate consequences by reducing released particulate material in high temperature and fire conditions.

If the desired safety function is to reduce the particulate matter by a specific amount (e.g., 99%), then the numeric reduction value should be documented within the technical basis versus use of an arbitrary or published value (e.g., 99.97%). Use of arbitrary published values in the technical basis for risk reduction may introduce additional constrains with the potential to prevent selection of a potentially better suite of controls. If a safety function is identified for a filter to survive elevated temperatures during a fire and reduce released particulate by 99%, then a ceramic filter is a clear an easily defensible choice. If possible, it is best to derive a simple and robust control structure which does not rely on the addition of secondary controls or protective measures.

Incorporation of secondary controls into the technical basis may cloud the overall intent and clarity of the primary control and overall control structure. When selecting ceramic filters over traditional (paper) HEPA filters, the technical basis would not require discussion of addition of secondary controls (e.g., sprinklers, demisters) to protect against high temperature or fire conditions. Consideration for control design and limitations should be considered throughout the HA and AA process. The HA and AA should explore unique effluent hazards (e.g., high temperature, burning

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[6] Protective Action Criteria

[7] Acute Exposure Guideline Level

[8] Emergency Response Planning Guideline

[9] Temporary Emergency Exposure Guideline

embers, moisture, corrosives) in addition to radioactive material. Controls should be evaluated in various different accident scenarios to determine how the control will protect a given receptor.

The potential for control optimization may play a larger role when designing and constructing a new facility versus when making modifications to an existing facility, process, or structure. When in the conceptual design phase, case studies, nonstandard, and eccentric control strategies may be explored within the HA and AA processes. The suite of controls may be developed based and right sized based on the results of the HA and AA process versus the engineering judgement of the process and design engineer.

## 2.6 Control Valuation

When documenting "value" in the technical basis for controls listed in the HA or AA, output must be commensurate with the performance criteria for the control. For example, the performance requirement may be defined as a ceramic filter surviving a temperature of X degrees Celsius (°C) for a period or unit of Y time (e.g., 400°C for 15 minutes or 500°C for 1 hour). Supporting analysis (e.g., fire hazard analysis) may be used to determine the performance criteria and define the parameters of the technical basis (e.g., fire duration, temperature, combustible loading, control areas). There may be additional reference material and date to support the technical basis and defined functional requirements and performance criteria for a given control/control strategy.

**Figure 1**, shows photographic evidence of the how a ceramic filter responds under certain fire conditions.

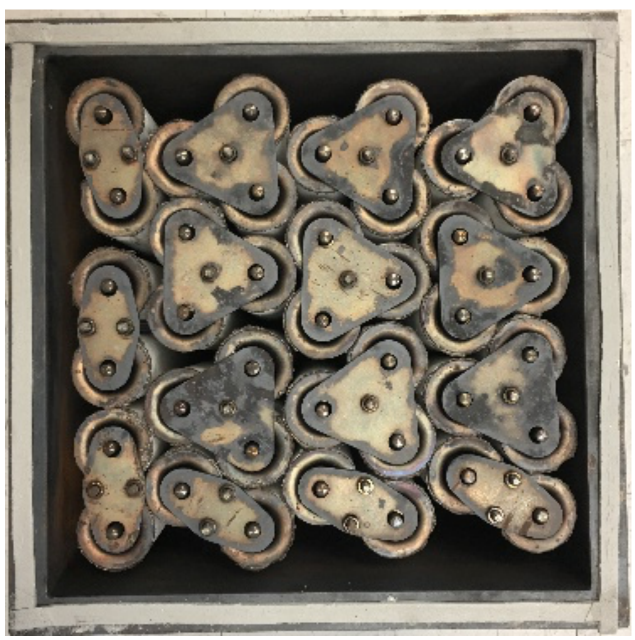

**Figure 1**. Ceramic filter after 1 hour at 500°C

The value of the control supports the safety function and performance criteria for risk reduction based on the HA and AA. When defining control valuation, consider key design parameters for engineered and administrative controls; hostile environments encountered by controls (normal, abnormal, and accident conditions); the combination of both engineered and administrative parameters; and simplification of the control suite.

If an engineered control cannot withstand caustic or acidic environments, then utilize an administrative control to prohibit caustics or acids. If stakeholders cannot operate the process under the limited parameters (e.g., caustics or acids are part of the nature of the operation), then an engineered control must be designed to withstand caustics and/or acids.

If an SSC is designed to protect another SSC, clearly define each safety function, performance criteria, with separate surveillances. For example, a ceramic prefilter can stop burning embers from damaging a credited (paper) HEPA filter. An additional example provides two (2) banks of filters in series; ceramic filters protecting traditional paper, or two (2) banks of ceramic filters.

Consider within facility and process improvements if existing controls can be substitute for a control utilizing new technology with additional benefits. Determine what additional analysis or design changes might be required to implement modifications. Consider if previously protected or credited controls still require protection.

When evaluating controls, always approach from the perspective of achieving maximum risk reduction. Just because a control is commercially available, does not mean that control is the only option for use. Many facilities create custom designed controls to fit their unique parameters. These unique control strategies may be socialized throughout the complex and advances may be made on a widespread scale. For example, just because a 12-foot (ft) ladder is commercially available, does not mean a 12 ft ladder is the tool for the job. Maybe there is a stairway, maybe there is an elevator, maybe the stairway is made of concrete that can survive a fire in the facility, maybe the elevator provides an advanced feature. This process is innovation.

The HA and AA processes have matured over time. If a facility is processing radioactive material, then the HA and AA must fully address the potential effluent during normal operation, abnormal operations, and accident conditions. The different effluents become the hazards for analysis within the HA and AA process. Define analysis parameters and control requirements, consider all potential hazards, establish a creative and cohesive control set for effective risk reduction. If needed, "stack" controls to meet design parameters. For example, if one filter meets 50% of the parameter, then place two filters in series to meet the design parameter. Consider controls on a holistic level and analyze the potential benefit from a pressure relief device to prevent a pressurized release and thus a lower release fraction in the accident analysis process. Consider use of scrubbers for toxic or corrosive gases. Consider pre-filters to protect credited primary filters. When establishing baseline requirements in the control derivation process include all potential parameters for consideration.

## 2.7 Fires

In addition to the HA and AA in support of the DSA, many facilities are also required to develop a Fire Hazard Analysis (FHA) in accordance with fire protection requirements. An FHA follows many of the same basic HA steps however, the FHA has a different purpose than the DSA and supporting analysis (e.g., HA, AA). The FHA describes the facility, identifies control areas, fire barriers, fire detection and suppression system parameters, defines combustible loading and chemical limitations, and additional life safety parameters. The FHA is not analogous to the AA developed in support of the DSA. The FHA does not model fire loading of combustible material to confirm the temperature and time a fire barrier can withstand a fire. For additional information on the relationship between the FHA and AA, refer to EFCOG Best Practice #204, *Combustible Loading Limit Restricts Fire Size to the SSC Capability within the Fire Protection Area*, Ronald Beaulieu and David Payne. Fire modeling can evaluate the survivability of the ceramic filters or lack of survivability of traditional paper filters under high temperature and fire conditions.

Consider details of combustible loading, ventilation (oxygen rich vs oxygen deficient), and other details of the fire progression. Conservative bounding values for realistic fire conditions at nuclear facilities can be 400°C (for a fast fire) to 500°C (for an ultra-fast fire) for a few minutes (LLNL-CONF-698278). Fires can happen at different locations in a facility, each with a different length of ductwork to the final exhaust filter bank. Testing filters at 400°C and 500°C for 1 hour is an established and conservative approach to bound the complexity of a facility fire with multiple airstreams from different locations converging on a final exhaust filter.

Consider conclusions of *Temperature-Time Curves for Real Compartment-Fire Conditions* (LLNL-CONF-698278). Compartment ventilation plays a big role on how large a fire can grow and the maximum temperature that can be attained in the compartment. Combustible loading contributes to fire growth for as long as ventilation is available to support full combustion. When compartment becomes ventilation limited, the combustible loading contributes only to duration of the fire. Use of combustible loading based on ASTM E 119 curve for establishing Specific Administrative Controls is overly conservative. Compartment fire modeling should consider the volume and geometry of the fire area, the type and configuration of construction materials that form the fire area boundary, the amount and type of combustible materials involved in the fire as well as effects of ventilation and fire suppression.

## 3. Performance Criteria and Control Limitations

Each control has benefits and limitations. In understanding the benefits of controls limitations and vulnerabilities must also be discussed within the technical basis. Key attributes of the control and limitations of the control may play a major role in the control selection process

Consider DOE-STD-3009 hierarchy of controls (nuclear facilities) and 10 CFR 851 hierarchy of controls (worker protection). New filter technologies can provide more resilient, passive controls close to the hazard. DOE-STD-3009-2014 discusses the criteria for selection of SS and SC controls and the expectation to withstand the accident event.

Filters are generically described as passive engineered controls. Fire and water damage to traditional (paper) filters is an ongoing challenge when developing a technical basis for control structures. Ceramic filters are resilient passive engineered controls which can withstand multiple hazards (e.g., elevated temperature, burning embers, moisture, corrosives, etc.). Ceramic filters provide robust, passive safety protection that can be located close to the hazard. Filters and filter systems are often credited controls within the HA, AA, and DSA. HEPA filters are the most commonly used and credited type of filters, but they are not the only type of filters. New technologies involving filters and air filtering devices of a variety of levels of filtration (e.g., HEPA, pre-filter). This paper offers best practices in how lessons learned from case studies can be implemented in the safety basis community.

## 4. Case Studies

New technologies in filters and air cleaning devices can provide a resilient and passive solution for radioactive air contaminants and other hazardous effluents. Filters and filter systems are often used as "credited" (SS or SC) controls within the HA, AA, and DSA for U.S. DOE Nuclear facilities. Traditional (paper) HEPA filters are the most commonly used and credited type of filters, however they are not the only filter choice available. New technologies involving filters and air filtering devices of a variety of levels of filtration (e.g., HEPA, ULPA, pre-filter, less than 99.97% filtration efficiency) have proven effective for risk reduction strategies within the HA and AA supporting the DSA.

Traditional (paper) HEPA filters must be adequately protected to ensure sustained functionality in a variety of operational parameters, including abnormal and accident conditions. Key attributes and limitations should be fully defined within the technical basis. Traditional (paper) HEPA filters are negatively affected by water, moisture, corrosive, pressure pulses. In contrast, ceramic filters can survive elevated temperatures, moisture, and burning embers impinging on the face of the filters.

When choosing appropriate filters and air cleaning devices within the safety basis documentation (i.e., HA, AA, DSA), consideration should be given to various parameters in addition to the overall risk reduction. If secondary controls are required to protect the key attributes of a credited control, the control may not be as robust as described within the technical basis. Consideration for overall lifecycle costs (e.g., operational, waste disposal, maintenance, surveillance) may also be contributing factors in the selection criteria.

### 4.1 Case Study #1 – Fires at Rocky Flats

Throughout the complex, there are historical examples of unanticipated problems resulting from the failure of controls or the exposure of controls to abnormal or accident conditions. Examples are documented within the photographs from the 1959 and 1967 fires at Rocky Flats. **Figure 2**, shows the destruction of a traditional (paper) filter following a fire, while **Figure 3**, shows the destruction of a traditional (paper) filter from fire suppression system in association with a fire.

**Figure 2**. Destroyed Filter Bank after a Fire

**Figure 3**. Water Damage to Filters Following a Fire

Consider the design parameters of the credited SSCs (paper filters) in a fire scenario atmosphere. The fires at Rocky Flat provide a case study for control suite selection. The paper filters were designed for a process where the effluent was always dry (temperature and humidity-controlled atmosphere in the Rocky Maintain desert). However, in the event of a facility-wide fire scenario, a water-based fire suppression system is relied upon to mitigate the fire progression to a catastrophic failure (e.g., minimal damages, sustainable repairs). In the 1959 fire event, burning embers propagated through the ventilation system , reached the paper filters, and ignited causing the catastrophic damage shown in **Figure 2**. In the 1967 fire event, the presence of heat, smoke, and flames engaged the fire suppression system, releasing water into the facility, and creating the conditions for a potential criticality event based on unfavorable geometry. The effluent reduction system thus required a "credited" fire suppression. The credited fire suppression system in turn required "credited" Raschig rings for unfavorable geometry tanks and a criticality alarm system. This series of credited controls was established to ensure effluent reduction. **Figure 3**, shows the catastrophic damage caused by the fire suppression system to the paper filters.

At Rocky Flats, controls utilizing water were deployed, but those controls had the potential to create an accident type (i.e., criticality). The potential for inadvertent criticality required the development of additional control strategies (e.g., borated Raschig rings, unfavorable geometry tanks), which were difficult to maintain and test. Maintenance and testing on the new suite of criticality controls was necessary to ensure the structural integrity of control suite remained intact over time. The TSR surveillance requirements and inservice inspection (ISI)validates the control has retained its credited "value" over the life of the facility (or control). Use of an alternative control strategy could have greatly simplified the control suite for effluent reduction and eliminated the self-imposed accident condition of inadvertent criticality within he filter banks. the control suite implemented at Rocky Flats for effluent reduction could have been greatly simplified.

A ceramic filter can withstand the challenges of fire, high temperature, and moisture conditions. With use of a ceramic filter system, a credited fire suppression system would not be required. Favorable tank geometries and borated Raschig rings would also not be identified as required. A criticality control system in the tanks would not be required. The TSR surveillance requirements and ISI on the credited systems would not be required. All of these components have initial, operational, maintenance, and inspection/surveillance costs. Hot breaks to switch out filters has costs, impact on schedule and mission, and risk of exposure of personnel to contamination. The longer life of a ceramic filter, and resistance to moisture and corrosion, would minimize the frequency of filter change out and thus hot breaks. This longer life and reduction in filter change out also reduces the amount of nuclear waste requiring treatment and disposal. The waste disposal costs per filter significantly outweigh the purchase price of the filter. Utilization of ceramic filter scan result in a significant lifecycle operational cost reduction while achieving the same level of effluent reduction (or more) and being a more reliable, passive system with engineered controls.

Start with a traditional (paper) filter at 99.97% efficiency for a certain lifetime, influenced by the presence of moisture. The exact lifespan has been a subject of debate as discussed in a number of recent studies (e.g., MSU ICET, Southwest Research Institute, PNNL). A ceramic filter would not have this reduction in operating life. Two (2) ceramic filters with a lower filtration efficiency put in series could achieve the same effluent reduction as the single traditional (paper) filter. Water based fire suppression systems are not required to protect the ceramic filters due to the inherent physical differences in ceramic versus paper filters.

### 4.2 Case Study #2 – Revising Hazard Analysis, Accident Analysis, and Documented Safety Analysis Chapters to Reflect Application of Ceramic High-Efficiency Particulate Air Filters

The use of HEPA filters are common in DOE facilities to reduce the effluent particles from heating ventilation and air conditioning systems. HEPA filters come in many sizes and shapes and have many applications in gloveboxes, downdraft tables and other ventilation applications.

Many nuclear facilities have a DSA with integral or supporting HA tables to document the postulated events/accident scenarios for HA progression into AA and design basis accidents; and in some cases, beyond design basis accidents. These HA tables evaluate plausible events/accident scenarios and credit controls between the unmitigated (uncontrolled risk rank) and the mitigated (controlled risk rank) to develop a suite of controls. The suite of controls provides the framework for the tolerable mitigated and residual risk for the given receptors.

Each control should have a documented risk reduction value . Given that risk is a product of likelihood and consequence, each control could have a value of likelihood (frequency) or consequence (mitigation) reduction. A single control should not be assigned both a frequency and consequence reduction. The reduction value for a HEPA filter or other type of effluent filter would be defined as a consequence reduction, as a credited component in the HVAC system. In a quantitative or semiquantitative risk analysis, the value of the consequence reduction is proportional to the efficiency of its filtration and the number of HEPA filter banks used. In general, the more HEPA filter banks used or the greater the filter efficiency, the greater the effluent particles reduction and proportionally the greater the "valuation" of the consequence reduction.

The credited value of a HEPA filter may be one (1) "bin" of consequence reduction for a filter with an efficiency of 99%. The filter may be procured to an efficiency of 99.5% or 99.7% to ensure the quality meets or exceeds the expected efficiency. The technical basis for consequence reduction is documented in the HA portion of the DSA and is approved via a Safety Evaluation Report (SER). A typical table for consequence reduction applicable to HEPA-filtered ventilation system is shown in **Table 1**.

**Table 1.** Summary of Approximate Consequence Reductions, Given in Number of Qualitative Bin Drops

| **Control (Safety-SSC or SAC)** | **Appropriate Consequence Reduction** | **Control (Safety-SSC or SAC)** |
|---|---|---|
| HEPA-filtered ventilation System (Safety-SSC) | 1-Bin | One (1)-bin for scenarios involving release of particulates to the public. Not applicable to HEVR scenarios.<br>One (1) bin is considered conservative for HEPA filtration systems, as their efficiencies generally exceed 99%.<br>HEPA-filtered Buildings, Glovebox, Downdraft Table |

Note: Although a HEPA filter bank may have a greater filter efficiency for quantitative or semiquantitative risk analysis, the increased consequence reduction is not equivalent to an additional "bin drop" in a qualitative or semiqualitative risk analysis approach.

When conducting the HA or AA consider alternatives to traditional paper filters, such as ceramic filters. One reason for such consideration is the use of filter media in environments where paper media could be adversely affected by high temperatures, fires, or acidic effluents (i.e., embers). A more robust media could ensure effluent filtration would continue to function under harsh environmental conditions (e.g., high temperatures, fire, flood). A ceramic filter could provide one (1) bin of consequence reduction for a filter with an efficiency of 99%. Two (2) ceramic filters in series, each with an efficiency of 90%, would have a combined efficiency of 99%. The ceramic filter(s) have a greater potential to survive hot embers from a fire in the nuclear facility as compared to a paper media HEPA filter, which may burn through and provide no filtration when needed during an accident progression.

A filter that survives an accident (e.g., elevated temperature, fire, flood) in the nuclear facility is arguably more robust and a "better" choice for the credited control suite than a filter that does not withstand an accident progression. Although a single ceramic filter has a lower filtration efficiency than a traditional (paper) HEPA filter, when considering controls in abnormal and accident conditions, the reliability and the survivability may provide a favorable alternative choice. When qualitative benefits and limitations of a ceramic filters and traditional (paper) HEPA filters are compared in fire conditions, the surviving ceramic filter is better than no efficiency for a burned-out paper filter. The potential to place these filters in series by using two (2) or more filter banks could provide enhanced confidence of filtration efficacy during normal operations and during accident conditions.

## 5. Safety Basis Integration

The DSA should document the document the site characteristics; facility description; HA, AA, and Control Selection; safety SSCs; derivation of TSRs; prevention of inadvertent criticality; and safety management programs in the level of detailed required to obtain a SER from the local U.S. DOE site office. Chapter 1 of the DSA describes the general requirements, site description, demography, environmental description (metrology, hydrology, geology) natural event accident initiation (natural phenomenon hazards), man-made external accident initiators, nearby facilities, and the validity of existing environmental analyses.

Chapter 2 of the DSA describes the facility and the processes that will be conducted in it, in support of hazard identification, hazard and accident analysis, and selection of hazard controls. Details of SSCs and the types of work to be performed in the facility should be included. Information regarding the facility specific design of the ventilation system and filtration (e.g., ceramic and/or paper filter) should be included. Supporting documentation, such as Applicable design codes and standards, design documents, and system design description is referenced sufficiently to provide the reader with a complete description of the SSCs relevant to the facility and processes.

Chapter 3 of the DSA provides information on the evaluation of normal, abnormal, and accident conditions to show compliance with the requirements of 10 CFR 830. This chapter describes the process used to systematically identify hazards, categorize the facility, and evaluate the potential internal, man-made external, and natural phenomena events that could trigger accidents. These accidents are then evaluated to understand impacts within the facility, onsite and offsite and the need for SC and SS controls. This evaluation also includes a determination of the need for SS controls for chemical accidents and protection of the collocated worker. Topics addressed include hazard identification, hazard categorization, HE, AA, and control selection. Chapter 4 of the DSA provides information on the SSCs necessary to protect the public and workers and to provide major contributions to defense-in-depth. Details are provided on Specific Administrative Controls that significantly reduce the risk of specific accidents. The chapter also describes the attributes (functional requirements and performance criteria) required to support the safety functions identified in the hazard and accident analyses and to support subsequent derivation of TSRs.

Highlights for SSC consideration are listed below. Details for these key points are in DOE-STD-3009-2014 and the corresponding training material from the DOE National Training Center.

- Safety function should tie together how the SSC works and how the SSC is credited in the HA and AA. Every safety function for each control clearly ties back to the HE or AA. Some safety functions may tie to different hazard scenarios which lead to multiple safety functions.
- Performance criteria should tie to testing of the SSC in situ in the facility.
- Performance criteria should tie to the value of the control.
- Functional requirements should be identified to fulfill safety functions. Such requirements are specified for both the SC and SS SSC and any needed support for the credited SSC. Functional requirements are to be described only for the specific accident(s) where the credited SSC is required to function.

Evaluate the field condition of the SSC for potential vulnerabilities or other engineering considerations (e.g., resistance to other hazards like moisture or corrosives or loss of power) to determine if it will survive hazard and accident conditions. Chapter 5 of the DSA provides information necessary to support the safety basis requirements for the derivation of TSRs in 10 CFR 830. This chapter describes how TSRs are derived using the information in the previous two chapters (Chapter 3 and Chapter 4). The information in this chapter demonstrates how the selected TSRs comply with 10 CFR 830.205. Further guidance can be found in DOE Guide 423.1-1, *Implementation Guide for Use in Developing Technical Safety Requirements*.

Testing via surveillance requirement or ISI must tie to the performance criteria in an active ventilation system. Surveillance requirements provide information necessary to derive testing, calibration, or inspection activities to assure necessary quality of systems and components is maintained and facility operations remain within safety limits, limiting control settings, and limiting conditions of operation. This information is used in developing the TSR Bases Appendix, which ties back to the SSC information in DSA Chapters 3, 4, and 5.

## 6. Conclusion

This Best Practice is focused on nuclear facility applications. The use of a HI, HE and control selection are applicable in both nuclear and high or moderate hazard industrial and less than hazard category 3 radiological facilities. The value of controls and use of passive filters are also universally applicable to industrial facilities. Thus, this practice could be applied in many facilities where hazardous effluent should be mitigated via filtration. Filters are typically considered as a passive design feature. The written information should address safety functions, performance criteria, and periodic surveillance of filters and air cleaning devices

Traditional (paper) filters provide 99.97% filtration efficiency (safety function) but will not survive a fire. Ceramic filters will, however, survive a fire. If the safety function of the ceramic filter is to survive the fire, consider the potential for risk reduction when additional hazards (e.g., elevated temperature, fire, flood) do not impinge on the overall control design strategy. A creative approach could arrange a ceramic filter bank and paper filter bank in series. The effluent reduction could combine the two safety functions for the overall ventilation system (survive fire and filter at 99.97% efficiency). The analyst could alternatively choose to use solely the ceramic filter and take credit for the appropriate level of the control (survive fire and documented level of filtration efficiency for particular ceramic filter).

When deriving controls in the HA and AA in support of a DSA (or other like documentation), explore a cohesive approach utilizing new and existing technologies. Benefits include risk reduction, lifecycle cost reduction, cohesive control suite throughout the HA, AA, and DSA, and improvements in safety to receptors.

## 7. Authors

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– Appendix –

DOE-HDBK-1163-2020, *Integration of Multiple Hazard Analyses.*

DOE-HDBK-1169, *Nuclear Air Cleaning Handbook.*

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