Contract No. and Disclaimer:

Identification of Appropriate Qualification Testing and End-of-Life Waste Storage Considerations for Deep Bed Sand (DBS) Filters

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Abstract

Deep bed sand (DBS) filters have filtered radioactive particulates at two United States Department of Energy (DOE) sites since 1948. Some early DBS filters experienced issues with chemical attack on support tiles, requiring significant repairs. Designs of DBS filters constructed since 1970 paid greater attention to chemical compatibility, resulting in decades of reliable performance since 1975.

The Defense Nuclear Facilities Safety Board has recently indicated that sand filters should be considered for new large processing facilities. The new Pit Disassembly and Conversion Facility (PDCF) at DOE's Savannah River Site (SRS) in South Carolina is being constructed with a DBS filter for final filtration, and new missions may call for more DBS filters to be constructed. However, at present there is no single point of reference for the design of DBS filters.

An American Society of Mechanical Engineers (ASME) project team was established by letter ballot in 2006 to draft a new code section, FL Sand Filters, for inclusion in ASME AG-1, *Code on Nuclear Air and Gas Treatment*.[1] This new code section is limited in scope to the type of DBS filters used in the United States currently at SRS, and previously at other DOE sites. The purpose of this paper is to discuss the issues the FL Sand Filter Project Team has identified with regard to DBS filters. These issues include: 1) identification of appropriate qualification testing to determine DBS filter seismic response, in-place efficiency, and particle loading; and 2) end-of-life waste storage requirements of DBS filters.

Introduction

DBS filters were first applied as radiological filtration at the DOE Hanford Site in Washington State in 1948. Several processing facilities at Hanford were provided with DBS filters. Two additional DBS filters were constructed in the 1950s at the DOE Savannah River Site (SRS) in South Carolina to support reprocessing facilities. In later years, several more DBS filters were constructed at SRS reprocessing and material storage facilities.

The early DBS filters at SRS experienced issues with chemical attack on concrete support tiles, requiring significant repairs. Designs of DBS filters constructed since 1970 paid greater attention to chemical compatibility. Since 1975, SRS has experienced over 200 filter-years with no significant issues.

Interest in DBS filters has increased in recent years. The Defense Nuclear Facilities Safety Board has indicated that sand filters should be considered for new large processing facilities. The new PDCF at SRS is being designed with a DBS filter for final filtration. The potential exists for additional DBS filters to be constructed as new missions are developed. The lack of a single point of reference for the design of DBS filters underscores the need for a new code section in ASME AG-1.

Scope of ASME AG-1 Code Section, *draft* FL Sand Filters

Since the 1940s, sand filters have been utilized by many countries to filter radioactive particulates.

The United States, Europe, and Japan currently employ sand filters for the following uses:

1. SRS uses DBS filters, with a capacity of 70,000 to 200,000 cubic feet per minute of air flow, for final filtration to capture radionuclide particles from the confinement ventilation exhaust system. The application of these filters is for continuous operation over a long term with large air flow volumes. Specific examples of SRS DBS filters include:
    - F Canyon constructed in 1953, supporting separation of plutonium/uranium materials and conversion to solid form
    - H Canyon constructed in 1954, supporting hardened nuclear chemical separation
    - Savannah River National Laboratory constructed in 1973
    - Defense Waste Processing Facility constructed in 1983, supporting conversion of liquid nuclear waste to solid glass form
2. Europe (France, Germany, and Sweden) use small, modular sand filters for the emergency exhaust of power reactors. The exhaust from the pressure vessel relief is filtered via a sand filter prior to atmospheric discharge. The application of these filters is considered short term with high velocity with small air flow volumes.
3. Japan uses sand filters for the venting systems of their power reactors; however, specific site usage is not published information.

ASME AG-1 new code section, FL Sand Filters, is being written based on the most current application of a DBS filter for large air volumes in removal of radioactive particulates in the United States. Additional code sections addressing sand filters such as those used in Europe and Japan may be written at a later date.

Qualification Testing of DBS Filters

Seismic Qualification. To be credible in modern nuclear facilities, it is necessary to conduct seismic qualification testing or perform equivalent design analysis. The

International Atomic Energy Agency and, in the United States, DOE and the Nuclear Regulatory Commission (NRC) have requirements for seismic qualification of new and existing nuclear facilities. These requirements apply to site selection and design and construction of each DBS filter structure. ASME AG-1 specifies seismic design and testing requirements for air and gas treatment components; specific qualification tests are outlined in AG-1 Section AA. Seismic qualification tests for DBS need to address parameters such as:

1. <u>Loss of proper stratification (sand sifting down to the bottom of the DBS filter)</u>. Because sand is the medium that will filter contaminants from the exhaust stream, loss of proper stratification of the media will affect filtering efficiency. Thus, a section of the DBS filter would need to be modeled, constructed, and tested in accordance with AG-1 Article AA-4350.[2]

2. <u>Soil-pressure-type loads on the walls (natural soil loads versus sand filter media loads on the DBS filter walls)</u>. The floor, ceiling or roof, and walls of the DBS filter must contain and retain the filtering media and function as a housing. Therefore, the DBS filter structure shall be designed and qualified in accordance with the requirements of American Concrete Institute 349, *Code Requirements for Nuclear Safety-Related Concrete Structures*.[3] Additionally, Component Service Levels and Load Combinations per AG-1 Article AA-4000[4] shall be considered. Qualification testing may be required to define load differences between natural soil and DBS filter media.

Comparable Filter Function Tests. Safety Class functions need to be periodically tested to confirm that the functions are within the defined bounds. For high-efficiency particulate air (HEPA) filtration systems, ASME AG-1[5] requires the following types of tests:

- Differential pressure
- Airflow distribution
- Visual inspection
- Air-aerosol mixing
- In-place leak

1. <u>Differential Pressure and Airflow Distribution</u>. The differential pressure test and the airflow distribution test can be accomplished to the intent of AG-1 for DBS filters.

2. <u>Visual Inspection</u>. Visual inspection of the DBS filter outlet area can also be accomplished to the intent of AG-1; however, inspection of the inlet area of a DBS filter is much more difficult. Indeed, some inspections have indicated that the inlet structure of a DBS filter at SRS has changed from the as-installed condition. The question then becomes: Should AG-1 FL Sand Filters require some means to inspect the DBS filter inlet area?

3. <u>Air-Aerosol Mixing</u>. There are two issues for discussion regarding air-aerosol mixing testing and DBS filters: First, the air-aerosol mixing test for HEPA filtration systems in AG-1[6] requires: "…that the challenge aerosol or gas

injection ports, used for the in-place leak tests…provide a uniform challenge across the entire face of the HEPA filter…". Further, the concentration readings are required every 2 feet. In the context of a DBS filter such as the one currently being designed for installation at the PDCF, this requirement would equate to approximately 18,000 gas-measuring locations across the DBS filter; however, one could most likely justify a less dense injection and sampling matrix.

Second, having any injection ports or sampling locations directly upstream of the media face is an impractical requirement for DBS filters. Current practice has the injection ports and sample port locations far upstream of the face of the DBS filter. There is a tortuous path from the injection point to the face of the DBS filter, such that there is little assurance that the challenge agent concentrations measured represent what actually gets to the filter face. As a result, the air-aerosol mixing test for the DBS filter cannot meet the intent of the same test required for the HEPA filtration systems in AG-1, and different tests or differently designed tests are needed for DBS.

4. In-Place Leak. The in-place leak test in AG-1 relies on a successful air-aerosol mixing test. Until the inlet challenge gas concentrations are clearly defined for a DBS filter, a rigorous determination of the DBS filter leak rate is not possible. In any case, the 0.03% leak rate of 0.3-micrometer (µm) particles required for HEPA filtration systems needs to be modified for a DBS filter. (Safety basis calculations use a DBS filter leak rate of 0.49% of 0.7-µm particles; however, efficiency tests have shown a lower filter leak rate. Thick sand layers could also improve efficiency.)

Particulate Loading Considerations. Limited testing has been performed to establish the particulate loading capacity of DBS filters. Testing has been previously conducted at SRS[7] and at the Hanford Site[8] to simulate smoke loading conditions for DBS filters.

The SRS tests were conducted using a 2-foot square sand filter assembly having an upward flow configuration with successively coarser layers of aggregate toward the base of the test unit. The test assembly was operated at an air flow velocity of 5 feet per minute (fpm). The initial filter pressure drop was nominally 4.8 inches (in.) of water. A carbon black "Raven 15" powder was selected to model smoke, as it was determined to be representative of the particle size spectrum for various combustible fuel categories of interest (e.g., neoprene gloves, vinyl tile, Benelex®, vinyl hose, Lucite®, Ultrasene®). The carbon black powder was fed until the pressure drop across the filter reached 15 in. of water, which was defined as the useful life of the filter. The smoke capacity, as measured by the carbon black testing, was determined to be 1.23 pounds per square foot of filter area, as identified in Figure 12 of the SRS paper presented at the 12th Atomic Energy Commission Air Cleaning Conference.[9] Based on the test pressure drop data, the pressure rise at the ¼ in. to #8 mesh layer and its interface with the #8 to #20 mesh aggregate layer was the limiting factor for filter performance.

The testing at the Hanford Site used various upward flow sand filter media configurations, air flow velocities of 5 and 10 fpm, and methylene blue smoke as the smoke source. The first test unit omitted the coarser layers of aggregate (i.e., the 1¾ in. to

5/8 in. and the ¾ in. to #4 mesh) at the base of the test assembly and was operated at an air flow velocity of 10 fpm. It was observed that these layers provide "considerable protection" to the #4 to #8 mesh aggregate layer based on subsequent testing with their inclusion. The other two test assemblies, which used both coarser layers of aggregate, were operated at a nominal air flow velocity of 5 fpm to replicate normal DBS filter operating conditions. Testing was terminated as the filter total pressure drop approached 8 in. of water. The average reported particulate loading of both test filters was nominally 123 grains per square foot, or 0.018 pounds per square foot of filter area. This is substantially less than the testing conducted at SRS. The predominant pressure drop was observed to occur at the #4 to #8 mesh aggregate layer or at its interface with the #8 to #20 mesh aggregate layer. Subsequent inspection of the sand indicated a heavier concentration of methylene blue at the interface of the two aggregate layers. Based on an increase in the measured pressure drop at the #4 to #8 mesh aggregate layer and then a subsequent decrease during testing, it was speculated that material initially collected in the #4 to #8 mesh aggregate layer was redistributed to its interface with the finer #8 to #20 mesh aggregate layer.

Based on the sand filter test data discussed above, it can be concluded that there is general agreement as to what DBS filter aggregate layers / interfaces primarily act to collect particulates. However, while DBS filters provide a robust control for fire events in that they are relatively insensitive to elevated approach temperatures and burning ember hazards, further testing of their particulate loading capacity is warranted.

Waste Storage Requirements of Abandon-In-Place

Even though most DBS filter documentation assumes that the end-of-use condition would be to abandon the DBS filter in place, there is concern about whether this practice would be acceptable to current regulators. The DOE Nuclear Air Cleaning Handbook[10] even states the following: "Present Government regulations for radioactive solid waste, though unclear, may rule out such in-place disposal [of DBS filters] in the future." Therefore, if the Design Basis Accident for the DBS filter assumes significant quantities of toxic or radioactive materials, which would be retained in the DBS, the design documentation must address this concern.

Some of the questions that need to be answered are:

1. If the Design Basis Accident assumes that kilograms of plutonium oxide may be deposited in the DBS filter, what would need to be included in the design to provide reasonable assurance that the regulators would accept the abandon-in-place position?
    - Would a double-wall containment be required if groundwater could get into the sand and gravel medium?
    - Would some type of groundwater collection system be required in the annulus between the double wall to detect leaching of the plutonium oxide?
    - Would some type of remote inspection technique be required to inspect for cracks in containment?

2. Does the requirement of 10 Code of Federal Regulations (CFR) 61.56 that discusses stability of the waste mean that the DBS filter media would need to be mixed with cement and water in order to meet long-term storage requirements?
3. Would all of the long-term performance objectives of 10 CFR 61, Subpart C, apply and need to be met?
   - Protection of the general population from releases of radioactivity
   - Protection of individuals from inadvertent intrusion
   - Stability of the disposal site after closure
4. Would the selected location of the DBS filter need to meet all of the near-term surface disposal requirements of 10 CFR 61, Subpart D?
   - Disposal site suitability requirements for land disposal
   - Disposal site design for land disposal
   - Land disposal facility site closure
   - Environmental monitoring
   - Waste classification
   - Waste characteristics
   - Labeling
   - Institutional requirements

Path Forward for ASME AG-1 Code Section, *draft* FL Sand Filters

Qualification Testing. The FL Project Team proposes to address the qualification testing issues identified above as follows:

1. A more comprehensive smoke loading test is warranted. Such a test could be conducted with a mock-up such as that described below, or in a unit with a smaller length and width, but still having the full height of the media layers. Smoke should be injected into the air stream until the filter fails, presumably by clogging the filter beyond the ability of the exhaust fans to overcome the load. This test will provide an absolute smoke loading capacity. The use of mock-ups can also validate the selection of specific media for the DBS filter.
2. A large-scale sand filter mock-up is needed to support seismic calculations. This mock-up should be the full height of the actual DBS filter and contain each aggregate layer (matching type and depth). The mock-up should be as long and wide as can be supported by a shake table apparatus. The mock-up should include the corresponding portion of the distribution and support structure. This test will provide validation of the response of the filter structure and media to a Design Basis Earthquake. The mock-up will also provide needed information on the load exerted on the filter structure by the media.
3. Air-aerosol mixing concerns may be addressed by the use of special test sections within the bed of the sand filter. These test sections should be channels approximately 2 feet square that pass vertically through the sand bed. They should be filled with the same types and depths of media as the rest of the sand filter. The test sections should be provided with taps to allow the test aerosol upstream and

downstream of the test sections to be measured. The number and placement of the test sections should provide a representative assessment of the entire filter.

4. Radiological conditions upstream of a sand filter will likely preclude human entry to inspect these locations. If upstream inspections are deemed necessary, provision should be made to support remote or robotic inspection.

Waste Storage Requirements of Abandon-In-Place. The FL Project Team proposes to address the issues identified above with regard to Design Basis Accidents, 10 CFR 61.56, 10 CFR 61 Subpart C, and 10 CFR 61 Subpart D as follows:

1. A cautionary note will be included in the code section, FL Sand Filters, that alerts the owner and designer of the DBS filter to the issues that need to be raised and adjudicated with regulators on a case-by-case basis to address a) the application of abandon-in-place (e.g., double-wall containment, remote inspection techniques, groundwater collection system), b) 10 CFR 61.56 requirements for waste stabilization (e.g., potential mixing of cement and water with the DBS filter media), c) 10 CFR 61 Subpart C long-term performance objectives, and d) 10 CFR Subpart D technical requirements for land disposal facilities.
2. The FL Sand Filters code section will include a non-mandatory appendix that discusses DBS filters in the context of the long-term performance objectives of 10 CFR 61 Subpart C and the near-term surface disposal requirements of 10 CFR 61 Subpart D.

References

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4. **ASME**: Code on Nuclear Air and Gas Treatment AG-1, Article AA-4000, Component Service Levels and Load Combinations, pp 12-25. (Standard) New York, NY, 2009.
5. **ASME**: Code on Nuclear Air and Gas Treatment AG-1, Table TA-4610, Moisture Separator, Prefilter, and HEPA Filter Acceptance Tests, pp 563. (Standard) New York, NY, 2009.
6. **ASME**: Code on Nuclear Air and Gas Treatment AG-1, Mandatory Appendix TA-V, Air-Aerosol Mixing Test Procedural Guidelines, pp 585-588. (Standard) New York, NY, 2009.
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8. **U.S. Department of Energy(DOE)**: Filtration of Radioactive Aerosols by Glass Fibers – Part 1, HW-20847, April 16, 1951, Hanford Works, Richland, Washington.
9. **Schurr, G.A., D.B. Zippler, and D.C. Guyton**: Deep-bed filter performance tests, 12th Atomic Energy Commission (AEC) Air Cleaning Conference, Figure 12, Pressure versus grams of carbon black (sand filter smoke simulation), p. 612. January 1973, DPSPU 72-30-5.
10. **DOE**: DOE Nuclear Air Cleaning Handbook, DOE-HDBK-1169-2003. November 2003.