PROBLEMS WITH THE LABORATORY TESTING OF NUCLEAR-GRADE ACTIVATED CHARCOAL

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Abstract

The staff has issued three emergency technical specification (TS) changes to licensees that had determined that the tests they performed were not in compliance with their TS, because the required testing standards and test protocols did not support a test in which the temperature is changed as required by the TS. As a result of the emergency TS changes, the NRC staff performed an internal survey of TS of operating plants which indicated that at least one-third of operating reactor licensees may be out of compliance with their TS. In addition, recent available laboratory test results demonstrated that testing of nuclear-grade activated charcoal to certain standards does not provide assurance for complying with the plant's licensing basis as it relates to onsite and offsite dose limits.

The staff proposes to resolve this situation by issuing a generic letter to all licensees. The proposed generic letter will request all licensees to review their TS and amend as necessary to come into compliance with their licensing basis. The staff will process license amendment requests in the normal manner, with an opportunity for hearing. This course of action may result in a situation in which a licensee is not in compliance with its TS until the staff processes the license amendment. Therefore, the staff intends to exercise enforcement discretion in certain situations.

The proposed generic letter[1] was published in the *Federal Register* on February 25, 1998 to solicit public comment. A total of 141 public comments were received from 24 letters. Of these, 95 were redundant, leaving 46 distinct comments. The staff is currently resolving the 46 distinct comments.

Background

Safety-related air-cleaning units used in the engineered safety feature (ESF) ventilation systems of nuclear power plants reduce the potential onsite and offsite consequences of a radiological accident by adsorbing radioiodine. To ensure that the charcoal filters used in these systems will perform in a manner that is consistent with the licensing basis of a facility, most licensees have requirements in their facility TS to periodically test (in a laboratory) samples of charcoal taken from the air-cleaning units.

The U.S. Nuclear Regulatory Commission's (NRC) and the nuclear industry's understandings of the appropriate laboratory tests for nuclear-grade charcoal have evolved over the years since the issuance of Regulatory Guide (RG) 1.52[2], "Design, Testing, and Maintenance Criteria for Postaccident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants," which is referenced in many plant TS. It was initially assumed that high-temperature/high-relative humidity (RH) conditions were the most severe. Later, with more testing experience, it became clear that the most conservative test is at low

temperature/high humidity. The use of outdated test protocols or inappropriate test conditions can lead to an overestimation of the charcoal's ability to adsorb radioiodine following an accident.

Problems associated with the performance of the laboratory test of charcoal under inappropriate test conditions were discussed in Attachment 1 of Information Notice (IN) 86-76[3], "Problems Noted in Control Room Emergency Ventilation Systems." Attachment 1, "Summary of Control Room Habitability Reviews," noted that charcoal was being tested at much higher temperatures than any expected during the course of an accident, and that the performance of the laboratory test at that temperature can result in erroneously high efficiency measurements.

In 1982, the American Society of Mechanical Engineers (ASME) Committee on Nuclear Air and Gas Treatment (CONAGT) conducted an inter-laboratory comparison test using American Society for Testing and Materials (ASTM) standard D3803-1979[4], "Standard Test Methods for Radioiodine Testing of Nuclear-Grade Gas-Phase Adsorbents," and found that seven U.S. laboratories and eight foreign laboratories obtained vastly different results when testing samples of the same charcoal. After efforts to resolve the differences failed, the NRC contracted with EG&G at Idaho National Engineering Laboratory (INEL) to assess the problem. As a result of this assessment, the NRC issued IN 87-32[5], "Deficiencies in the Testing of Nuclear-Grade Activated Charcoal." Through IN 87-32, the NRC informed licensees of deficiencies in the testing of nuclear-grade charcoal, specifically noting serious problems with the capabilities of the testing laboratories and with the testing standard (ASTM D3803-1979). The NRC contractor detailed the specific problems in its technical evaluation report, EGG-CS-7653[6], "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program." Specifically, EG&G reported that ASTM D3803-1979 had unacceptable test parameter tolerances and instrument calibration requirements, and that ASTM D3803-1979 was nonconservative in not requiring humidity pre-equilibration of used charcoal. The information notice indicated that the protocol developed by EG&G could be utilized for performing the laboratory test until the D-28 committee responsible for ASTM D3803 revised the standard. The committee completed the revision and issued it in December 1989[4]. The problems associated with the testing laboratories were resolved after the number of U.S. firms performing such tests dropped from seven to the current two.

On April 29, 1993, representatives from ASME and CONAGT met with the NRC staff to express their concerns about laboratory testing of charcoal. CONAGT discussed the variation in laboratory test results obtained (methyl iodide penetration) when temperature, RH, face velocity, bed depth, test protocol, and impregnate were varied. CONAGT stated that ASTM D3803-1989, "Standard Test Method for Nuclear-Grade Activated Carbon," is the only acceptable test method for TS applications and compared the results of laboratory tests performed using the 1986 version of ASTM D3803[4] (which is the 1979 version with editorial changes) to results using the 1989 version. The results from the 1986 protocol showed significantly higher iodine-removal capabilities than the results from the 1989 version.

In addition, CONAGT indicated that testing charcoal at temperatures greater than 30°C almost always results in the charcoal meeting the TS acceptance criteria, even when the charcoal is deficient. To support this premise, CONAGT presented the results of laboratory tests conducted at temperatures of 30°C, 80°C, and 130°C. The data show significant increases in iodine-removal capabilities as the test temperature increases. CONAGT indicated that all systems located outside of containment should be tested at 30°C, which is more representative of the limiting accident conditions. Tests conducted at 80°C or 130°C are inappropriate because tests at these temperatures result in the regeneration of

the charcoal. As the temperature of the charcoal is increased, there is an increase in the reaction rate which results in the charcoal being able to adsorb more iodine than it could at lower temperatures. Therefore, testing at the elevated temperatures results in an overestimation of the actual iodine-removal capability of the charcoal, and testing at 25°C or 30°C gives results that represent a more realistic assessment of the capability of the charcoal. CONAGT concluded its presentation by stating that the major problems associated with the laboratory test of charcoal are the designation of the test protocol and the TS that designate the test to be performed.

On November 6, 1996, the staff visited the two remaining laboratories that test nuclear-grade activated charcoal, NCS Corporation and NUCON International, Inc.. Both laboratories have resolved the poor reproducibility problem identified in the EG&G report by performing all tests with calibrated equipment that is capable of maintaining the tight tolerances of the test parameters as specified in ASTM D3803-1989. Tight tolerances are very important when tests are performed at high RH, because slight variations in RH result in unacceptably large differences in the tested efficiency of the charcoal.

Charcoal Testing Requirements

Analyses of design-basis accidents assume a particular ESF charcoal filter adsorption efficiency when calculating offsite and control room operator doses. Licensees then test charcoal filter samples to determine whether the filter adsorber efficiency is greater than that assumed in the design-basis accident analysis. The laboratory test acceptance criteria contain a safety factor to ensure that the efficiency assumed in the accident analysis is still valid at the end of the operating cycle.

Guidance on the frequency of, and the test method for, the laboratory testing of charcoal appears in various documents, including all revisions of RG 1.52 and other NRC documents on plant TS. Guidance on the laboratory test protocol appears in such standards as American National Standards Institute (ANSI) N509[7], "Nuclear Power Plant Air-Cleaning Units and Components," ANSI N510[8], "Testing of Nuclear Air-Cleaning Systems," Military Specification RDT M 16-1T[9], "Gas Phase Adsorbents for Trapping Radioactive Iodine and Iodine Components," and ASTM D3803.

All of the standards describe a pre-equilibration period, a challenge period, and an elution period. During the pre-equilibration (pre-sweep) period, the charcoal is exposed to a flow of air controlled at the test temperature and relative humidity (RH) before the challenge gas is fed through the charcoal. The pre-equilibration period ensures that the charcoal has stabilized at the specified test temperature and RH for a period of time, which results in the charcoal adsorbing all available moisture before the charcoal is challenged with methyl iodide. During the challenge period, air at the test temperature and RH with radio-labeled methyl iodide is injected through the charcoal beds to challenge the capability of the charcoal. During the elution (post-sweep) period, air at the test temperature and RH is passed through the charcoal beds to evaluate the ability of the charcoal to hold the methyl iodide once it is captured.

The ASTM D3803-1989 standard has two additional testing periods that are not required by other standards: the stabilization period and the equilibration period. During the stabilization period, the charcoal bed is brought to thermal equilibrium with the test temperature before the start of pre-equilibration. During the equilibration period, air at the test temperature and RH is passed through the charcoal beds to ensure the charcoal adsorbs all the available moisture before the feed

period. During this period, the system is more closely monitored than in the pre-equilibration period to ensure that all parameters are maintained within their limits.

Depending upon the plant's TS, typical test temperatures are usually one of the following: 25°C, 30°C, 80°C, or 130°C. In addition, the TS usually require that the test be conducted at 70-percent RH if the ESF system controls the RH to 70-percent or less, or at 95-percent if the RH is not controlled to 70-percent.

The standard technical specifications (STS) and many plant-specific TS specify Regulatory Position C.6.a of RG 1.52, Revision 2, as the requirement for the laboratory testing of the charcoal. Regulatory Position C.6.a refers to Table 2 of RG 1.52. Table 2 references Test 5.b of Table 5-1 of ANSI N509-1976. Test 5.b references the test method from paragraph 4.5.3 of Military Specification RDT M 16-1T (date not indicated), but specifies that the test is to be conducted at 80°C and 95-percent RH with preloading and postloading sweep at 25°C. This test is referred to as the "25-80-25 test." The essential elements of this test are as follows:

- 70-percent or 95-percent RH
- 5-hour pre-equilibration (pre-sweep) time, with air at 25°C and plant-specific RH
- 2-hour challenge, with gas at 80°C and plant-specific RH
- A 2-hour elution (post-sweep) time, with air at 25°C and plant-specific RH

The latest acceptable methodology for the laboratory testing of the charcoal is ASTM D3803-1989. ASTM D3803-1989 is updated guidance based on an NRC verification and validation effort on ASTM D3803-1979, which is updated guidance based on RDT M 16-1T. The essential elements of the ASTM D3803-1989 test are as follows:

- 70-percent or 95-percent RH
- 2-hour minimum thermal stabilization, at 30°C
- 16-hour pre-equilibration (pre-sweep) time, with air at 30°C and plant-specific RH
- 2-hour equilibration time, with air at 30°C and plant-specific RH
- 1-hour challenge, with gas at 30°C and plant-specific RH
- 1-hour elution (post-sweep) time, with air at 30°C and plant-specific RH

The major differences between the ANSI N509-1976 and ASTM D3803-1989 standards for charcoal testing are shown in Table 1.

Table 1 Differences Between ANSI N509-1976 and ASTM D3803-1989

	ASTM D3803-1989	ANSI N509-1976
Pre-Equilibration (Pre-Sweep) Temperature	30°C	25°C
Challenge Temperature	30°C	80°C
Elution (Post-Sweep) Temperature	30°C	25°C
Total Pre-Test Equilibration	18 hours	5 hours
Tolerances of Test Parameters	Smaller	Larger

As stated above, ASTM D3803-1989 challenges the representative charcoal samples at 30°C rather than at 80°C. The quantity of water retained by charcoal is dependent on temperature, and less water is retained as the temperature rises. The water retained by the charcoal decreases its efficiency in adsorbing other contaminants. At 30°C and 95-percent RH, charcoal will retain about 24 to 25 weight-percent water. At 80°C and 95-percent RH, charcoal retains only about 19 to 20 weight-percent water. Because most charcoal is anticipated to be challenged at a temperature closer to 30°C rather than 80°C, the lower temperature test condition of ASTM D3803-1989 will yield more realistic results than would a test performed at 80°C.

ASTM D3803-1989 specifies a test temperature of 30°C for both the pre- and post-test sweep rather than 25°C. There is little difference in the adsorption behavior of charcoal between these two temperatures. A temperature of 25°C is more conservative; however, the increase from 25°C to 30°C does not represent a significant variation in the test results.

ASTM D3803-1989 provides results that are reproducible compared to RDT M 16-1T because it has smaller tolerances on various test parameters, and it requires that the charcoal sample be pre-equilibrated for a much longer period. The longer pre-equilibration time is more conservative because it will completely saturate the representative charcoal sample which ensures reproducibility of the results by having every charcoal sample begin the test at the same initial conditions. Therefore, testing in accordance with ASTM D3803-1989 will result in a more realistic prediction of the capability of the charcoal.

TS Testing Reference

Laboratory tests of the charcoal are typically required (1) once every refueling outage, (2) when certain events occur that could adversely affect the ability of the charcoal to perform its intended function, and (3) following a defined period of ESF system operation. The TS require demonstration by laboratory testing that the charcoal is capable of performing at a level greater than that assumed in the licensee's dose analysis. If it fails to perform at that level, the charcoal must be replaced.

The determination of the appropriate test conditions, test protocol, and acceptance criteria for laboratory testing of nuclear-grade activated charcoal is frequently not a straightforward process. It sometimes requires a complex journey through a number of documents to ascertain the appropriate test conditions, test protocol, and acceptance criteria. As described earlier, if the plant has STS, the STS reference Regulatory Position C.6.a of RG 1.52 for the requirements for the laboratory testing of charcoal. Regulatory Position C.6.a refers to Table 2 of the regulatory guide. Table 2 references Test 5.b of Table 5-1 of ANSI N509-1976. Test 5.b from Table 5-1 references the test method from paragraph 4.5.3 of RDT M 16-1T (date not indicated), but specifies that the test is to be conducted at 80°C and 95-percent RH with pre-loading and postloading sweep at 25°C. This test is referred to as the "25-80-25 test."

Also contributing to the potential confusion are the various ways in which TS are written, and conflicting NRC guidance on testing, particularly NRC letters to the nuclear industry and NRC papers presented at national conferences. This problem arose from the evolving understanding of what constituted an appropriate test. At various times, the NRC has stated that the newest version of a standard can be used and the test can be conducted at a temperature of 30°C. At other times, the NRC indicated that the TS are requirements and that the tests must be performed at the 25-80-25 conditions. In various forums, the NRC has also stated that a technical argument may be made for

using the newer standard. However, in some instances when newer standards were utilized to demonstrate conformance with the TS, the NRC required licensees to submit TS amendment requests because the newer standards were not referenced in the TS. Therefore, it is understandable that licensees may be confused about laboratory testing protocols, testing conditions, and acceptance criteria. As a result, many licensees are not testing charcoal in accordance with their TS, although the tests they conduct may be more conservative than the tests required by the TS.

Additionally, the 25-80-25 test has difficulties in that none of the protocols in any version of RDT M 16-1T or ASTM D3803 addresses performing the laboratory test at multiple temperatures as required by ANSI N509-1976. If the test protocol described in paragraph 4.5.3 of RDT M 16-1T (1973) is followed verbatim, a thermal step change must be made after the 5-hour pre-equilibration period to increase the temperature from 25°C to 80°C for the challenge period. The problem with such thermal step changes is that they result in condensation forming on the charcoal. The condensation of free water in the sample bed is cause for aborting the test, according to the 1977 version of RDT M 16-1T and subsequent versions of ASTM D3803. Therefore, the 25-80-25 test cannot be performed pursuant to any existing test protocol.

Because paragraph 4.5.3 cannot be followed verbatim, a few licensees have changed the 25-80-25 test to thermally equilibrate the charcoal before introducing the challenge gas. Following the pre-sweep conditioning at 25°C, the bed temperature is raised to 80°C before introducing the challenge gas. Although such testing does not cause condensation in the test rig, it is not acceptable because the results are not easily reproducible, and even when the test is successfully completed, the results may not be conservative.

Section 2 of ANSI N509-1976 states for the various documents that supplement ANSI N509 that the issuance of a document in effect at the time of the purchase order shall apply unless otherwise specified. In the case of charcoal, the purchase order date could be considered the date that the charcoal is procured. Therefore, TS that have the STS wording may allow the licensee the flexibility to use a more recent laboratory protocol than the 1973 version of RDT M 16-1T, depending on the procurement date for the charcoal, without a TS change. However, although the flexibility of protocol selection exists, the requirement to perform a 25-80-25 test for those plants that have TS that reference either Revision 1 or Revision 2 of RG 1.52, Table 5-1 of ANSI N509-1976, or ANSI N510-1975 can only be relieved by license amendment.

Categorization of Plants

Since February 1996, the staff has issued three emergency TS changes to licensees that had determined that the tests they performed were not in compliance with their TS, because the required testing standards and test protocols did not support a test in which the temperature is changed as required by the TS. If the temperature in the test apparatus is changed from 25°C to 80°C during the test without modifying the test protocol, water condenses on the charcoal, thereby causing the test to be aborted (to fail). The emergency TS changes were issued for the V.C. Summer, Davis-Besse, and Oconee facilities. The details of these TS changes are discussed below.

On February 10, 1996, the licensee for the V.C. Summer Nuclear Station, South Carolina Electric & Gas Company (SCE&G), requested an emergency TS change. The systems involved were the control room emergency ventilation system and the fuel handling building exhaust system. On February 10, 1996, the NRC granted the emergency TS change. The emergency TS change was

requested because SCE&G had determined that laboratory tests of the charcoal of the control room ventilation system and the fuel-handling building system had not been performed in compliance with the V.C. Summer TS. The laboratory test performed for V.C. Summer was a 25-25-25 test in lieu of the 25-80-25 required by its TS. The licensee had been performing the 25-25-25 test because, in consultation with its testing laboratory, it concluded that performance of the 25-80-25 test would result in condensation on the charcoal and, thus, an invalid test.

On March 29, 1996, the Toledo Edison Company requested an emergency TS change for the Davis-Besse plant. The systems involved were the hydrogen purge, the shield building emergency ventilation, and the control room. The TS for Davis-Besse required the laboratory test to be performed in accordance with RG 1.52, Revision 2. In this case, the licensee was performing a 30-30-30 test using the testing protocol of ASTM D3803-1979 in lieu of the 25-80-25 test. On March 29, 1996, the NRC granted the emergency TS change to allow the 30-30-30 test.

On April 2, 1996, Duke Power Company requested an emergency TS change for the Oconee Nuclear Station. The systems involved were the reactor building purge, the spent fuel pool ventilation, and the penetration room ventilation. The TS for Oconee required the laboratory test of charcoal to be performed in accordance with ANSI N510-1975 and Method C of ASTM D3803-1979, which requires the performance of the test at 130°C and 95 percent RH. However, the licensee was actually performing a 30-30-30 test using the test protocol of ASTM D3803-1989. The NRC granted an emergency TS change on April 2, 1996, to permit the 30-30-30 test.

In each of these cases, the test performed to demonstrate compliance with TS provided results that the staff considered closer to reflecting the capability of the charcoal than the test required by the TS. In addition, the licensees believed that using the newer standard would satisfy their TS requirement. Their bases for this belief were the limitations of the test referenced in RG 1.52, their interpretation of ANSI N509 as allowing the use of later versions of the test protocol, and some of the guidance provided by the NRC. In the case of Oconee, the test actually performed is the test that the staff believes is the appropriate one, ASTM D3803-1989. However, because these tests had not been conducted in compliance with the plant's TS, each licensee would have had to shut down its plant or remain in a cold-shutdown mode until the test required by the TS could be successfully performed, or until the TS were amended.

On March 21, 1996, Carolina Power & Light Company flew a charcoal sample from the Brunswick standby gas treatment system (SGTS) to its testing laboratory in Ohio for the performance of the 25-80-25 test to comply with the Brunswick TS before restart of an idle unit. The Brunswick TS required that the laboratory tests be performed in accordance with Revision 1 of RG 1.52. Previously, the licensee directed its testing laboratory to perform an 80-80-80 test. To perform the 25-80-25 test, the laboratory equilibrated the charcoal to 80°C before introducing the challenge gas. The licensee has not requested a TS change for Brunswick to correct the problem and is awaiting guidance from the NRC.

As a result of the emergency TS changes, the staff has performed an internal survey of operating plant TS to determine whether other plants have the potential for similar problems with compliance. The survey indicated that at least one-third of operating reactor licensees may not be in compliance with their TS because they reference the flawed 25-80-25 testing protocol and may have used later

versions of the standards for the laboratory tests of their nuclear-grade charcoal. On the basis of this survey, the staff established the following four categories of plants:

(1) plants in compliance with their TS that test in accordance with ASTM D3803-1989

(2) plants in compliance with their TS that test in accordance with a test protocol other than ASTM D3803-1989

(3) plants not in compliance with their TS that test in accordance with ASTM D3803-1989

(4) plants not in compliance with their TS that test in accordance with a test protocol other than ASTM D3803-1989

The licensees in Group 1 have TS that require charcoal to be tested in accordance with ASTM D3803-1989, which adequately demonstrates the capability of the charcoal. The licensees in Group 2 have TS that require charcoal to be tested in accordance with test standards other than ASTM D3803-1989. The licensees that received emergency TS changes were in Groups 3 and 4. Licensees in Groups 3 and 4 have TS that require charcoal to be tested in accordance with the 25-80-25 test.

Proposed Generic Letter

Recent available laboratory test results for more than 50 charcoal samples demonstrated that there were significant differences in filter efficiencies for about 15 to 20 percent of the tested samples when comparing the test results from ASTM D3803-1979 and ASTM D3803-1989. When the charcoal samples were tested in accordance with ASTM D3803-1979, they always appeared to have very high efficiencies. However, when the same charcoal samples were tested in accordance with ASTM D3803-1989, significant reduction in efficiency was noted for about 15 to 20 percent of the tested samples. Depending on the system arrangement, this reduction in filter efficiency can result in calculated doses to the control room operators exceeding the General Design Criterion (GDC) 19[10] limits by as much as a factor of 1.5 to 2. For pressurized-water reactors (PWRs) with secondary containments and for all boiling-water reactors (BWRs), this reduction in filter efficiency can result in offsite iodine doses from a filtered pathway increasing by as much as a factor of 10 to 15. While most licensees have relatively new charcoal that is in good condition, the staff believes that a few licensees have old charcoal that is degraded and their TS-required test is ineffective in identifying the degradation. As a result, the staff has determined that testing of nuclear-grade activated charcoal to standards other than ASTM D3803-1989 does not provide assurance for complying with the plant's licensing basis as it relates to the dose limits of GDC 19 and Part 100[11].

The staff proposes to resolve this situation by issuing a generic letter to all licensees. The proposed generic letter will:

(1) Alert licensees that the NRC has determined that testing nuclear-grade activated charcoal to standards other than ASTM D3803-1989 does not provide assurance for complying with their current licensing basis as it relates to the dose limits of GDC 19 and Part 100.

(2) Request that all licensees determine whether their TS reference ASTM D3803-1989 for charcoal filter laboratory testing. Licensees whose TS do not reference ASTM D3803-1989 should either

amend their TS to reference ASTM D3803-1989 or propose an alternative test protocol and provide the information discussed in the requested actions section of the generic letter.

(3) Alert licensees of the staff's intent to exercise enforcement discretion under certain conditions.

(4) Require that all licensees send the NRC written responses to this generic letter, relating to implementation of the requested actions.

The staff will process license amendment requests in the normal manner, with an opportunity for hearing. This course of action may result in a situation in which a licensee is not in compliance with its TS until the staff processes the license amendment. Because of the (1) conflicting NRC guidance, (2) complex and ambiguous standards, and (3) licensee belief that using later versions of the standard would satisfy their TS requirements, the staff does not believe that certain licensees should be cited for willful violation of their TS. Therefore, the staff intends to exercise enforcement discretion in certain situations.

Public Comments

The proposed generic letter was published in the *Federal Register* on February 25, 1998 to solicit public comment. A total of 141 public comments were received from nineteen licensees, two industry organizations, two charcoal testing laboratories, and one individual. Of these, 95 were redundant, leaving 46 distinct comments. Of the 141, the following list provides the ten most frequently occurring comments:

1. The 60 day implementation period is too short.
2. The regulatory process was not followed properly, a full backfit analysis should be performed.
3. The cost associated with the generic letter is not justified under backfitting rule.
4. The role of a generic letter is to gather or disseminate information not to impose new requirements.
5. The generic letter may not be necessary in light of new source term.
6. Industry and NRC should work together on issue in a workshop.
7. Charcoal inside containment should be treated differently than outside containment.
8. Charcoal should be tested at actual accident conditions.
9 Submitting laboratory test results is an unnecessary burden.
10. The alternate test protocol is not a real alternative. The performance criteria should be based on the licensing basis not ASTM D3803-1989 and the existing test laboratories should be used to determine the acceptability of the alternate test protocol.

The staff is currently resolving the 46 distinct comments. After the generic letter is issued, the staff plans to revise RG 1.52 to be consistent with the generic letter.

References

1. U.S. Nuclear Regulatory Commission; "Laboratory Testing of Nuclear-Grade Activated Charcoal;" Federal Register: Vol. 63, No. 37; pages 9581-9589; Washington, DC 20555; (1998).

2. U.S Nuclear Regulatory Commission; "Design, Testing, and Maintenance Criteria for Postaccident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants;" Regulatory Guide 1.52; Revision 2; Washington, DC 20555; (1978).

3. U.S Nuclear Regulatory Commission; "Problems Noted in Control Room Emergency Ventilation Systems;" Information Notice 86-76; Washington, DC 20555; (1986).

4. American Society for Testing and Materials; "Standard Test Method for Nuclear-Grade Activated Carbon;" ASTM D3803-1979, 1986, and 1989; Philadelphia, PA 19103.

5. U.S Nuclear Regulatory Commission; "Deficiencies in the Testing of Nuclear-Grade Activated Charcoal;" Information Notice 87-32; Washington, DC 20555; (1987).

6. Scarpellino, C.D., and Sill, C.W.; "Final Technical Evaluation Report for the NRC/INEL Activated Carbon Testing Program;" EGG-CS-7653; Idaho Falls, Idaho 83415; (1987).

7. American Society of Mechanical Engineers; "Nuclear Power Plant Air-Cleaning Units and Components;" ANSI/ASME N509-1976; New York, NY 10017.

8. American Society of Mechanical Engineers; "Testing of Nuclear Air-Cleaning Systems;" ANSI/ASME N510-1975; New York, NY 10017.

9. USAEC, Division of Reactor Research and Development, Now USDOE, Office of Scientific and Technical Information, Oak Ridge, TN 37831; "Gas Phase Adsorbents for Trapping Radioactive Iodine and Iodine Components;" RDT M 16-1T-1973.

10. U.S. Nuclear Regulatory Commission; "Control Room;" General Design Criteria (GDC) 19; Title 10, Code of Federal Regulations (CFR), Part 50, Appendix A, Washington, DC 20555; (1971).

11. U.S. Nuclear Regulatory Commission; "Reactor Site Criteria;" Title 10, Code of Federal Regulations (CFR), Part 100, Subpart A; Washington, DC 20555; (1962).