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EPRI Groundwater Assessment for TVA's Sequoyah Nuclear Plant

Assessment Final Report

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Onsite Evaluation Dates: March 26, 2007 through March 30, 2007

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A. Introduction

An assessment of radioactive groundwater contamination at Sequoyah Nuclear Plant (SQN) and the groundwater protection program at Sequoyah was performed March 26 through 30, 2007. This assessment was sponsored by the Electric Power Research Institute (EPRI) and was conducted to:

- review the status of the investigations of radioactive contamination of groundwater performed to date,
- evaluate the interpretation of the available data,
- provide the SQN staff with recommendations for proceeding with the ongoing investigation, and
- provide recommendations for implementing the draft EPRI document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants" (March 2007).

The assessment included the following:

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1. Review of the radiological events contained in the files required by 10 CFR 50.75 (g).
2. Review of the documents prepared in support of the Nuclear Energy Institute (NEI) groundwater protection initiative.
3. Review of various hydrogeologic reports and investigations related to evaluation of the potential for impacts to groundwater.
4. Review of laboratory analytical data, including the results of recent analyses for radioactivity in groundwater samples collected from available monitoring wells.
5. Review of selected plant sketches and drawings.
6. Review of testing performed on the radioactive waste discharge pipe line.
7. A site tour.
8. Discussions with selected site personnel.

The assessment team members have extensive experience in groundwater investigations at commercial nuclear power plants. Their expertise includes radiological evaluations, plant operations, groundwater sampling and analysis, groundwater monitoring well design and installation, characterization of hydrogeologic flow domains, hydrogeologic interpretations of groundwater contaminant fate and transport, and non-destructive evaluations (NDE).

B. Summary Findings

Status of Investigations Completed to Date

The assessment team concludes that the presence of tritium and/or other radionuclides in the shallow aquifer at SQN poses no significant threat to the environment, to human health, or to any applicable regulatory criteria.

The recommendations presented in this assessment report are directed toward assisting the SQN staff in determining the sources of the radiological contamination that has been measured in groundwater at the site and to understand its distribution and movement in the environment. These recommendations are offered in the context of the currently evolving industry initiative and EPRI groundwater protection guidelines to better understand and report the impacts to groundwater from operations at nuclear power plants.

It is evident from the EPRI assessment that SQN has made substantial efforts to investigate impacts to groundwater and that a considerable volume of data pertaining to the distribution and movement of radiological contaminants at the site has been collected. **Approximately 25 groundwater monitoring wells are present at the site, and some have been sampled since 2003 for tritium and other radionuclides.**

A hydrogeological investigation of the industrial area of the SQN plant site had been completed shortly before the site visit of the EPRI assessment team. That investigation included sampling of groundwater in approximately 30 locations from small-diameter borings advanced below the water table with a Geoprobe. One-inch diameter monitoring wells were constructed in four of these Geoprobe borings. These and selected existing monitoring wells are sampled at various frequencies; some weekly and some monthly. A report summarizing the results of that investigation was expected during the middle of April, 2007 and was not available for review by the EPRI assessment team.

Interpretation of the Available Data

The available groundwater elevation and tritium concentration data for Well 31 suggest a correlation over time with the operation of the circulation water system and/or to changes in the elevation of the regional surface water system. The location of this well corresponds to sites of historical surface spills and contamination events, most notably the overflow of a sump in the Unit 2 Additional Equipment Building in 1998, and the discovery of radioactivity in soil at the outfall of the Unit 2 RWST moat drain pipe in 1995.

This possible correlation suggests that the observed trends in tritium concentration in groundwater may be associated with historical spills rather than an ongoing leak. Rising groundwater levels may remobilize tritium suspended within the vadose zone below the sites of the historical leaks. A potential leak in the radioactive waste discharge pipeline, which passes underground near Well 31, was suspected as the source, but this appears to have been disproved by hydro testing completed in 2006. Investigation of a potential leak in the fuel transfer canal (near Well 21) is in progress and has been inconclusive to date.

Proceeding With the Ongoing Investigation

(b)(4),(b)(5)

The evaluation team recommends that the following lines of inquiry be considered to further investigate the source(s) of tritium that have been measured in groundwater at SQN:

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(b)(4),(b)(5)

- (b)(4),(b)(5) All of the existing wells are relatively shallow, and are completed within the sediments overlying bedrock. (b)(4),(b)(5)

  (b)(4),(b)(5)

- Groundwater samples currently are collected either with small diameter bailers or with auto samplers. (b)(4),(b)(5)

  (b)(4),(b)(5)

  (b)(4),(b)(5) However, as discussed in greater detail below, both methods can introduce significant sampling bias to the analytical results for other radionuclides. (b)(4),(b)(5)

(b)(4),(b)(5)

- Analytical results provided by the Western Area Radiological Laboratory (WARL) are cu[redacted] concentration. [redacted] (b)(4),(b)(5)

(b)(4),(b)(5)

Implementation of the Draft EPRI Guidance Document

(b)(4),(b)(5)

(b)(4),(b)(5)

Similarly, in 2002 radioactivity was identified in the soil surrounding the Unit 1 RWST moat drain. Although contaminated soil was removed from this area based on measured concentrations of gamma-emitting radionuclides (primarily Co-58, Co-60 and Cs-137), tritium concentrations were not measured, and it is likely that a substantial volume of tritium remained in the soil. Wells 21, 29 and 31 are located several hundred feet from the Unit 1 RWST, in an inferred downgradient direction.

In 1998 a sump in the Unit 2 Additional Equipment Building overflowed, causing a release of radioactive liquid through a door and into the surrounding soil and a storm drain. Contaminated soil was removed to a depth of approximately one foot below grade. The extent of contamination was determined based upon measurement of the principal gamma emitters (Co-58, Co-60, Cs-134, Cs-137, and Mn-54) to a lower limit of detection of 5E-7 μCi/gram. However, tritium concentrations were not measured, and it is likely that a substantial volume of tritium remained in the soil. The area of the spill from the Unit 2 Additional Equipment Building is located to the east of the Unit 2 reactor containment building, in the vicinity of Wells 21, 29 and 31.

An evaluation of tritium concentrations and water levels in Well 31, and water levels in several nearby wells (Figure 1), shows a direct correlation between tritium concentrations in Well 31 and groundwater elevations. As groundwater levels in Well 31 rise and fall, so do tritium concentrations. Figure 1 shows that groundwater levels in Wells 31, 29 and 21 fluctuate up to approximately 7 feet on an annual cycle, with maximum and minimum levels occurring around July and January, respectively. These levels may correspond with the controlled flows in the Tennessee River (which also affect the water level in the cooling water discharge channel) and suggest a hydraulic connection of groundwater in these wells with flow in the river and/or the discharge channel.

Figure 1 shows that other wells west of the discharge channel (Wells 30, 32 and 33) have much smaller fluctuations in water levels, with little or no annual cycle apparent. This observation suggests that Wells 31, 29 and 21 may be hydraulically connected to the discharge channel by some natural stratigraphic feature or by some underground utility that provides a preferential flow path.

The observed patterns of groundwater levels and tritium concentrations in Well 31 suggest that rising groundwater levels may encounter tritium that was released to the soil during one or more of the historical surface spills noted above, and that is now suspended by capillary forces above the water table in the vadose zone. The rising water levels may remobilize a portion of the tritium, which contributes to the increased concentrations measured in groundwater sampled from the well during periods of high water levels.

Figures 2 and 3 show the variation in tritium levels in Well 31 during the periods spanning the last two refueling outages in Unit 2 and Unit 1, respectively. These figures show that tritium concentrations in Well 31 are lowest during the outages and increase immediately following the outages. Because the flow of cooling water is reduced during outages, it is likely that the water level in the discharge channel is lower during outages. Lower tritium levels in Well 31 during outages support the conceptual model of rising groundwater remobilizing tritium from historical surface spills that is suspended in the vadose zone.

(b)(4),(b)(5)

(b)(4),(b)(5) Confirmation of the presence of tritium in the soil would not dictate that it be removed immediately, but may provide an explanation for the observed distribution of tritium in groundwater.

(b)(4),(b)(5)

(b)(4),(b)(5)

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Figure 1

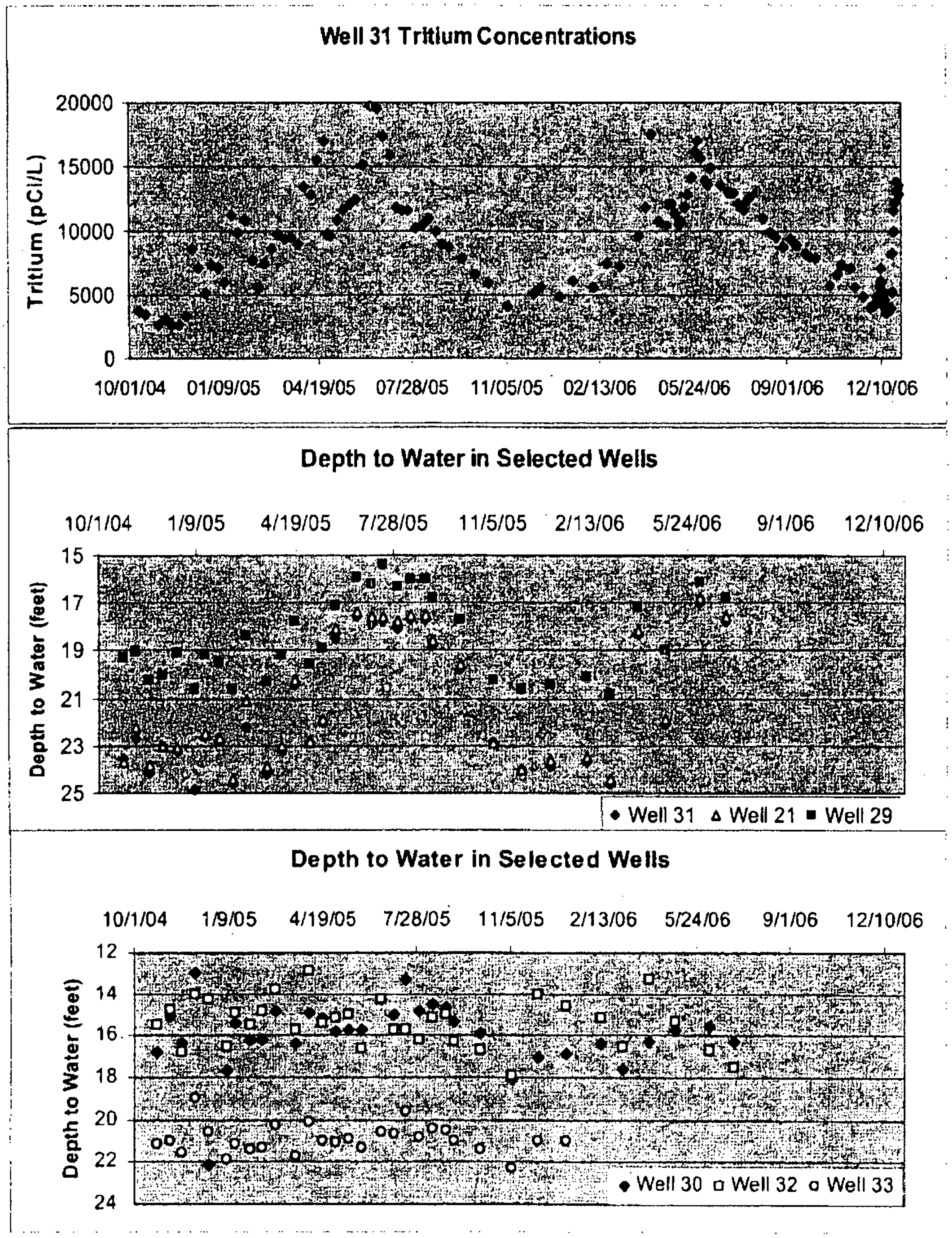

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Figure 2

Well 31 Tritium Concentration During Unit 2 Outage Ending December 26, 2006

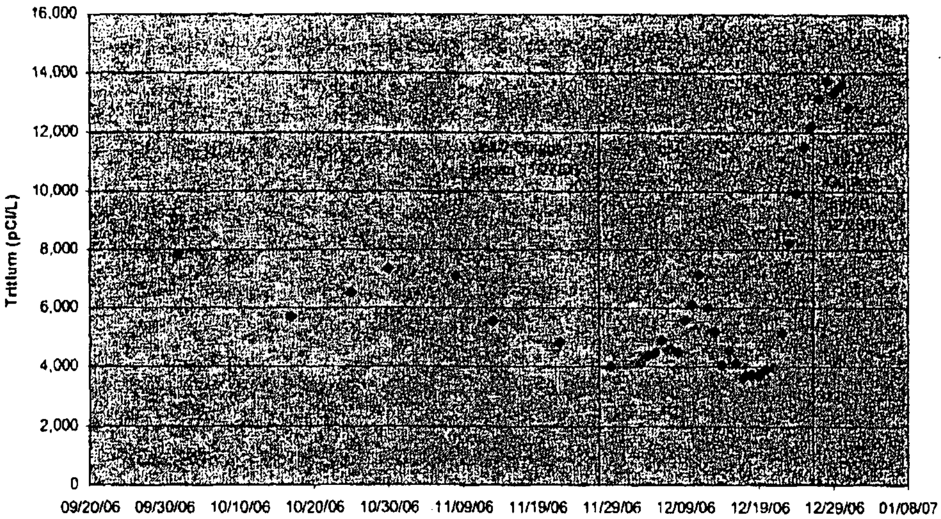
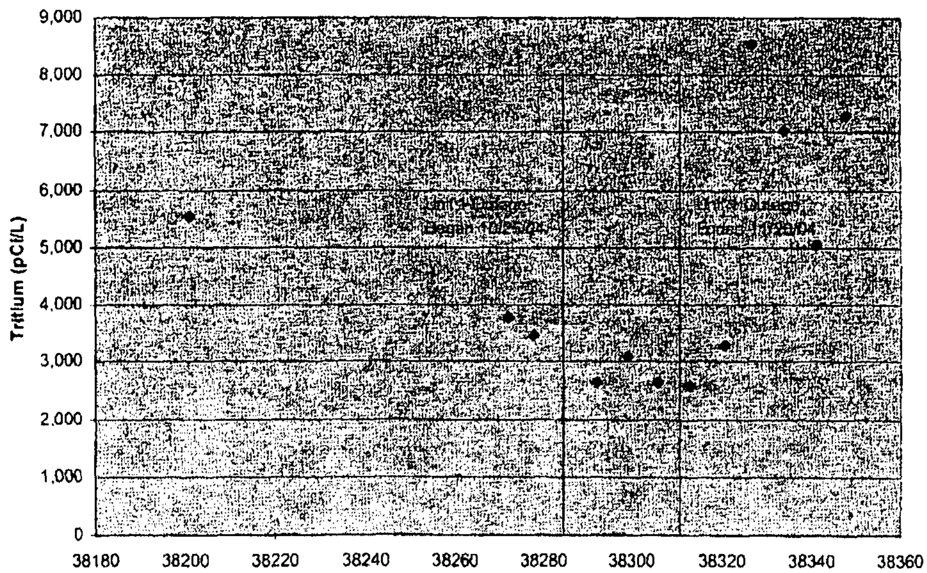


Figure 3

Well 31 Tritium Concentration During Unit 1 Outage Ending Nov 20, 2004

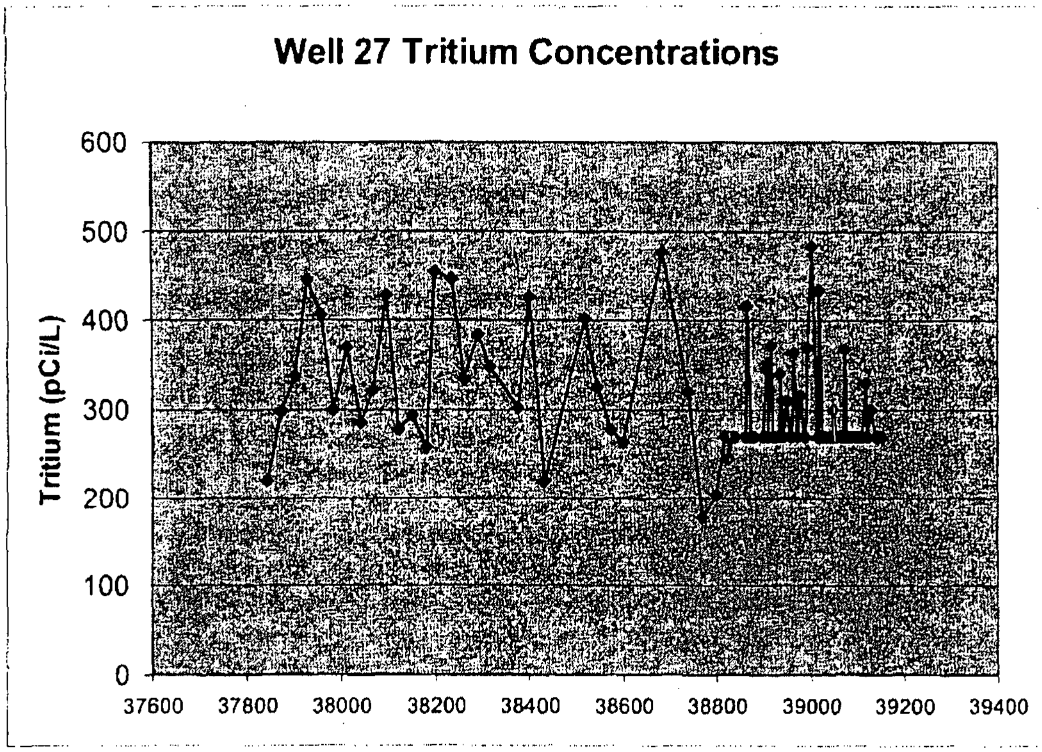


2.0 Evaluation of Elevated Tritium Concentrations Measured in Monitoring Well 27

Well 27 was installed in 2002 to monitor groundwater adjacent to the turbine building sump discharge pipeline. Initial quarterly samples from the well did not contain tritium. Tritium was first detected in Well 27 in September 2003. Since that time the concentration has fluctuated through a very narrow range from less than the MDC of 220 or 270 pCi/L, to a maximum of 484 pCi/L on October 17, 2006. Since December 2006, through the latest weekly sample (March 19, 2007) analyzed prior to the visit of the EPRI assessment team, tritium was virtually undetected in Well 27. Figure 4 shows the indistinct trend in tritium concentrations in this well.

(b)(4),(b)(5)

Figure 4



3.0 Evaluation of Elevated Tritium Concentrations Measured in Monitoring Well GP-13

In 1997, an estimated 600 to 1,000 gallons of radioactive liquid leaked from the Modularized Transfer Demineralization System (MFTDS) and were spilled to the rad waste yard immediately adjacent to the railroad bay door. The liquid influent to the MFTDS at the time of the spill contained 4.84E-2 μCi/ml (4.84E7 pCi/L) of radioactivity, which probably does not include the tritium inventory. However, it is reasonable to expect that the tritium concentrations ranged from 10^6 to 10^7 pCi/L. A french drain system ran parallel to the railroad tracks, and during the initial response to the spill, a vortex of spilled water was observed entering the drain in an area around rotted railroad ties.

Contaminated asphalt and soil and most of the french drain were excavated and removed, based on measured concentrations of gamma-emitting radionuclides (primarily Co-58, Co-60, Cs-134, and Cs-137). However, no attempt was made to remove concrete pads containing banks of electrical conduit that were contaminated, or to clean culverts with inaccessible contaminated soil. Although no measurements of tritium in soil were made during the remediation, it seems obvious that a substantial amount of tritium from this spill entered the soil and was not recovered.

Well GP-13 was installed during the recently completed hydrogeological study of the SQN plant site. This well is located in the area of the 1997 spill, along the former railroad immediately inside the radiological control area. Weekly groundwater samples from the well collected in February and March 2007 contained from 1.5E4 to 1.8E4 pCi/L of tritium.

(b)(4),(b)(5)

4.0 Analytical Data

Very few groundwater samples at SQN have been analyzed for any radionuclides other than tritium. As noted previously, Sr-90 is relatively mobile in the environment and its movement within the groundwater is only minimally retarded by adsorption to soil particles compared to almost all other radionuclides (except tritium). If an active leak from an SSC is ongoing, Sr-90 and/or other radionuclides may be present in the local groundwater. (b)(4),(b)(5)

(b)(4),(b)(5)

[redacted]

The Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) suggests the use of the "critical level" in identifying positive analytical activity. An approximation to the "critical level" is to apply a criterion of 2-sigma of the counting error rather than a 3-sigma criterion. Applying a 2-sigma (or "critical level") criterion to the identification of positive activity statistically results in approximately 5 percent of all analytical data being considered positive falsely (a Type 1 error). However, re-sampling to confirm a suspect result, trending the analytical data over a period of several sampling rounds, and consideration of the location of the sample relative to suspected source areas can usually eliminate most false positive results. (b)(4),(b)(5) [redacted]

(b)(4),(b)(5)

[redacted]

5.0 Procedures and Programs

The current groundwater protection program at SQN does not have a set of procedures to address the following elements:

- Sample planning
- Sample collection, storage, shipment, and chain-of-custody
- Selection of sample analytical suites, analytical methods, and sampling frequency
- Analytical DQOs, including specification of MDCs and criteria for defining positive detection of radionuclides
- Validation of analytical results
- Groundwater and monitoring well data management
- Monitoring well construction and monitoring well closure
- Monitoring well maintenance

In light of the Nuclear Energy Institute (NEI) Groundwater Initiative and the corresponding draft EPRI document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants", it is likely that the recently completed hydrogeological investigation at SQN will mature into a long-term monitoring program. (b)(4),(b)(5)

(b)(4),(b)(5)

6.0 Hydrogeological Database

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7.0 Groundwater Elevation Study With Data-Logging Pressure Transducers

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(b)(4),(b)(5)

8.0 Monitoring Well Preventative Maintenance Program

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9.0 Groundwater Sampling Frequency

(b)(4),(b)(5)

(b)(4),(b)(5)

10.0 Groundwater Sampling Methods

Groundwater at SQN is currently sampled with small diameter bailers (to fit into a 1-inch diameter well) or with auto samplers. If tritium is the only analyte of interest, either method is acceptable. However, both of these methods can introduce sampling bias to the analytical results for all other radionuclides, and adversely affect the ability to collect groundwater samples that are representative of *in situ* conditions.

Groundwater exists under relatively constant and uniform conditions of temperature and pressure. When a sample is collected and brought to the surface, where atmospheric conditions prevail, these physical parameters are changed. These changes induce changes in the solubility of gases, including oxygen and carbon dioxide, which are naturally present in groundwater. Loss of these gases results in an increase in pH, which reduces the solubility and possibly the concentration of many radionuclides potentially in solution.

The pressure decrease inherent in bringing a groundwater sample to the surface can be exacerbated by using suction-lift pumps (e.g., peristaltic pumps such as those in an auto sampler), particularly at lifts exceeding 15 feet, as these pumps may impart substantial negative pressure to the sample during collection. Samples subjected to relatively high ambient air temperature at the ground surface for extended periods, which may occur when using an auto sampler, can lose a significant percentage of dissolved gases, with resulting shifts in pH and redox state, that can induce precipitation of potentially dissolved radionuclides.

Unlike other radionuclides, tritium is not a solute in groundwater. Tritiated water is physically and chemically the same as normal water, except that tritiated water contains some molecules in which the normal hydrogen atom is replaced by tritium – the radioactive isotope of hydrogen. Because tritium is not a solute, changes in temperature and pressure induced during groundwater sampling do not affect its solubility or concentration.

In addition to changes in temperature and pressure, some groundwater sampling techniques may induce agitation and aeration of the sample or entrainment of particulate matter (turbidity). These effects are most pronounced with the use of bailers. Aeration alters the gas content of a sample, which induces changes in pH and solubility of solutes. Exposure of groundwater samples to atmospheric air can result in oxidation of the reduced form of iron (Fe^{2+}), which is common in most groundwater, and co-precipitation of other metals.

Agitation and increase of sample turbidity result in high concentrations of suspended particles to which radionuclides that are not mobile under natural groundwater flow conditions may be adsorbed. Because the amount of agitation and increased turbidity in samples from the same well can vary widely from sample event to sample event, the resulting analytical data for radionuclides present in the groundwater at trace concentrations (e.g., Co, Cs, Fe, Mn and Sr) can reflect spurious increases of these species. The apparent fluctuations in concentration can be large, and can complicate the evaluation of the meaning and significance of the data.

The goal in sample collection should be to use methods that result in the least impact possible to the chemical and physical properties of the water. The use of such methods will optimize efforts to obtain groundwater samples that result in analytical data that is accurate and reproducible, and that can be relied upon to make informed decisions regarding the impacts of contaminants. The accuracy and precision of sample analytical data are only as good as the quality of the samples submitted for analysis, and this quality is strongly controlled by the sampling method.

Many investigators have studied the effects of the method of sampling groundwater on the quality of the resulting analytical data. Although the method is not yet employed universally, a consensus among practitioners suggests that a method referred to as low-flow purging and sampling is the best currently available approach for collecting groundwater samples most representative of conditions within the aquifer. This method of sampling includes the following features:

- Use of a pump (often a gas-driven bladder pump) to purge and sample the well
- Placement of the pump intake within the middle of the wetted portion of the well screen
- Use of a low flow rate (approximately 200 ml/min) that induces no more than approximately 0.3 feet of drawdown during both purging and sampling
- Minimal disturbance of the stagnant water column above the well screen and of the accumulated sediment or colloids at the bottom of the screen

- Monitoring of water quality indicator parameters, including pH, temperature, conductivity, dissolved oxygen, and turbidity, during purging to determine when it is appropriate to collect a sample
- Minimization of sample agitation and atmospheric contact with the sample
- Collection of unfiltered samples for analysis of metals (including radionuclides) to allow estimation of the total contaminant load, which is comprised of both the dissolved and colloidal fraction in the groundwater

(b)(4),(b)(5)

11.0 Tritium-Saturated Concrete

Information from several decommissioning nuclear plants has demonstrated that tritium in contact with concrete diffuses into, and is retained within, the bulk structure of the concrete. In these situations, a tritium gradient generally exists, and this radionuclide has been measured in significant concentrations even at the center of concrete walls several feet thick. This phenomenon has important implications regarding the potential for impacts to groundwater. Concrete structures that have been in contact with high concentrations of tritium provide a reservoir that can be a source of the contamination in groundwater. (b)(4),(b)(5)

(b)(4),(b)(5)

12.0 Review of 10 CFR 50.75 (g) Files

Efforts have been made by SQN staff to document the spills and events that could lead to soil, groundwater, and surface water contamination that might persist until the time of decommissioning. From this effort, approximately eight events were identified and documented. The most significant of these events appear to be the following: a) a spill in 1997 from the MFTDS to the rad waste yard adjacent to the railroad bay door, b) the overflow in 1998 of a sump in the Unit 2 Additional Equipment Building, and c) the discovery of radioactivity in the soil near the outfall of the RWST moat drain pipe at Unit 2 in 1995, and at Unit 1 in 2002.

(b)(4),(b)(5)

13.0 Implementation of the March 2007 Draft EPRI Groundwater Guidelines

The draft EPRI guideline document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants" describes a process for characterizing impacts to groundwater and implementing a groundwater protection program. The process adopts a graded approach which recognizes that some sites will require more investigation than others. Of the three program levels, all sites are expected to implement the elements included in Program Level I. Sites that score a higher Priority Index, because their risk of having significant groundwater impacts is greater, are expected also to undertake additional investigative measures described in Program Levels II or III.

The following is a listing of the elements currently in the draft guideline document for Program Level I, with a brief discussion of how SQN has or should implement them. Although not specifically addressed here, the same baseline list of program elements is relevant to the implementation of a groundwater protection program at the Brown's Ferry and Watts Bar nuclear power plants.

(b)(4),(b)(5)

(b)(4),(b)(5) [redacted]

DQOs are used to establish performance and acceptance criteria, which serve as the basis for designing a plan for collecting environmental data of sufficient quality and quantity to support the goals of the study. (b)(6) [redacted]

(b)(4),(b)(5) [redacted] m

Approximately 25 monitoring wells have been installed at SQN to date. (b)(4),(b)(5) [redacted]

(b)(4),(b)(5) [redacted]

(b)(4),(b)(5)

An understanding of the construction details of a monitoring well is necessary when evaluating the results of analysis of groundwater samples collected from the well. The types of well construction details to be documented include:

- The drilling method
- The total well depth
- The depth interval over which the well is open to the aquifer (screen zone)
- The type and thickness of any filter material adjacent to the screen zone
- The type and thickness of any seal that isolates the screen zone from

(b)(4),(b)(5)

(b)(4),(b)(5) [redacted]

DQOs are used to establish performance and acceptance criteria, which serve as the basis for designing a plan for collecting environmental data of sufficient quality and quantity to support the goals of the study. (b)(6) [redacted]

(b)(4),(b)(5) [redacted]

(b)(4),(b)(5)

[redacted]

Tritium is always considered to be an analyte because of its abundance within primary cooling water and its mobility within groundwater systems. Those radionuclides with half-lives less than a few days generally are not of interest for groundwater monitoring. Similarly, those radionuclides that are relatively immobile in groundwater (e.g., Am, Cm and Pu) may be removed from the analyte list for selected sampling locations.

(b)(4),(b)(5)

[redacted]

Generally, the MDC for each analyte should be a small fraction of the lowest applicable regulatory criteria for that analyte.

It should be noted that in some instances the MDCs for analyses of REMP samples may not be low enough to achieve the DQOs of a groundwater sampling program. It should also be noted that while an existing 10 CFR Part 61 analyte list may be useful in the design of a groundwater protection program, the MDCs used for the Part 61 analyses also may not be sufficiently low enough to achieve the groundwater sampling DQOs.

(b)(4),(b)(5)

(b)(4),(b)(5)
[redacted]

(b)(4),(b)(5)
[redacted] Typical water quality indicator parameters include:

- Turbidity
- Temperature
- pH
- Oxidation-reduction potential (ORP)
- Specific conductivity
- Dissolved oxygen concentrations

In order to determine when a representative groundwater sample can be obtained, these indicators of water quality typically are measured periodically prior to collection of a sample. (b)(4),(b)(5) [redacted]

(b)(4),(b)(5)
[redacted]

(b)(4),(b)(5)

The analytical complications resulting from the presence of background radioactivity are distinct from those due to analytical bias. They are also unrelated to false-positive detections of radionuclides that are statistically predictable when analyzing at low environmental levels near the MDC.

Radionuclides found in background may be naturally occurring in the environment or may be of anthropogenic origin. Possible sources of background radioactivity in groundwater include the following:

- Minerals in soil and rock
- Cosmogenic processes in the upper atmosphere
- Atmospheric nuclear weapons testing
- Nuclear accidents such as at Chernobyl
- Releases of radionuclides from up-gradient nuclear power plants, hospitals, U.S. Department of Energy facilities, or other facilities that are sources of radioactive material
- Releases of radiochemical pharmaceuticals from up-gradient water treatment plants and landfills

(b)(4),(b)(5)

(b)(4),(b)(5) Controlled airborne releases from the plant ventilation stack or cooling tower may result in measurable atmospheric deposition of plant-related radionuclides (including tritium) in the vicinity of the owner-controlled area. Some of this material may accumulate on plant roof surfaces and wash into roof drains during precipitation events. Rain may also wash airborne releases onto the soil and building surfaces near the plant.

Discovery at SQN of radioactive contamination on the roof of the auxiliary building in the early 1990s is documented in the 10 CFR 50.75 (g) file. (b)(4),(b)(5)

(b)(4),(b)(5)

(b)(4),(b)(5)

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(b)(4),(b)(5)